New Textbook

Brad Postle

NOBA

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Contents

About Noba & Acknowledgements 4

Enter Section Title Name Here... 5

1 History of Psychology 6
David B. Baker & Heather Sperry

2 The Brain 23
Diane Beck & Evelina Tapia

3 Sensation and Perception 40
Adam John Privitera

4 Vision 65
Simona Buetti & Alejandro Lleras

5 Attention 81
Frances Friedrich

6 Failures of Awareness: The Case of Inattentional Blindness 96
Daniel Simons

7 Memory (Encoding, Storage, Retrieval) 108
Kathleen B. McDermott & Henry L. Roediger

8 Factors Influencing Learning 132
Aaron Benjamin

9 Forgetting and Amnesia 146
Nicole Dudukovic & Brice Kuhl

10 Eyewitness Testimony and Memory Biases 158
Cara Laney & Elizabeth F. Loftus

11 Categories and Concepts 172
Gregory Murphy

12 Judgment and Decision Making 192
Max H. Bazerman

13 Intelligence 207
Robert Biswas-Diener

14 Consciousness 222
Ken Paller & Satoru Suzuki

Index 239

About Noba

The Diener Education Fund (DEF) is a non-profit organization founded with the mission of re-inventing higher education to serve the changing needs of students and professors. The initial focus of the DEF is on making information, especially of the type found in textbooks, widely available to people of all backgrounds. This mission is embodied in the Noba project.

Noba is an open and free online platform that provides high-quality, flexibly structured textbooks and educational materials. The goals of Noba are three-fold:

- To reduce financial burden on students by providing access to free educational content
- To provide instructors with a platform to customize educational content to better suit their curriculum
- To present material written by a collection of experts and authorities in the field

The Diener Education Fund is co-founded by Drs. Ed and Carol Diener. Ed is the Joseph Smiley Distinguished Professor of Psychology (Emeritus) at the University of Illinois. Carol Diener is the former director of the Mental Health Worker and the Juvenile Justice Programs at the University of Illinois. Both Ed and Carol are award- winning university teachers.

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Enter Section Title Name Here...

1

History of Psychology

David B. Baker & Heather Sperry

This module provides an introduction and overview of the historical development of the science and practice of psychology in America. Ever-increasing specialization within the field often makes it difficult to discern the common roots from which the field of psychology has evolved. By exploring this shared past, students will be better able to understand how psychology has developed into the discipline we know today.

Learning Objectives

- Describe the precursors to the establishment of the science of psychology.
- Identify key individuals and events in the history of American psychology.
- Describe the rise of professional psychology in America.
- Develop a basic understanding of the processes of scientific development and change.
- Recognize the role of women and people of color in the history of American psychology.

Introduction

It is always a difficult question to ask, where to begin to tell the story of the history of psychology. Some would start with ancient Greece; others would look to a demarcation in the late 19th century when the science of psychology was formally proposed and instituted. These two perspectives, and all that is in between, are appropriate for describing a history of psychology. The interested student will have no trouble finding an abundance of resources on all of these time frames and perspectives (Goodwin, 2011; Leahey, 2012; Schultz & Schultz, 2007). For the purposes of this module, we will examine the development of psychology in America and use the mid-19th century as our starting point. For the sake of convenience, we refer to this as a history of modern psychology.

The earliest records of a psychological experiment go all the way back to the Pharaoh Psamtik I of Egypt in the 7th Century B.C. [Image: Neithsabes, CC0 Public Domain, https://goo.gl/m25gce]

Psychology is an exciting field and the history of psychology offers the opportunity to make sense of how it has grown and developed. The history of psychology also provides perspective. Rather than a dry collection of names and dates, the history of psychology tells us about the important intersection of time and place that defines who we are. Consider what happens when you meet someone for the first time. The conversation usually begins with a series of questions such as, “Where did you grow up?” “How long have you lived here?” “Where did you go to school?” The importance of history in defining who we are cannot be overstated. Whether you are seeing a physician, talking with a counselor, or applying for a job, everything begins with a history. The same is true for studying the history of psychology; getting a history of the field helps to make sense of where we are and how we got here.

A Prehistory of Psychology

Precursors to American psychology can be found in philosophy and physiology. Philosophers such as John Locke (1632–1704) and Thomas Reid (1710–1796) promoted **empiricism**, the idea that all knowledge comes from experience. The work of Locke, Reid, and others emphasized the role of the human observer and the primacy of the senses in defining how the mind comes to acquire knowledge. In American colleges and universities in the early 1800s, these principles were taught as courses on mental and moral philosophy. Most often these courses taught about the mind based on the faculties of intellect, will, and the senses (Fuchs, 2000).

Physiology and Psychophysics

Philosophical questions about the nature of mind and knowledge were matched in the 19th century by physiological investigations of the sensory systems of the human observer. German physiologist Hermann von Helmholtz (1821–1894) measured the speed of the **neural impulse** and explored the physiology of hearing and vision. His work indicated that our senses can deceive us and are not a mirror of the external world. Such work showed that even though the human senses were fallible, the mind could be measured using the methods of science. In all, it suggested that a science of psychology was feasible.

An important implication of Helmholtz's work was that there is a psychological reality and a physical reality and that the two are not identical. This was not a new idea; philosophers like John Locke had written extensively on the topic, and in the 19th century, philosophical speculation about the nature of mind became subject to the rigors of science.

The question of the relationship between the mental (experiences of the senses) and the material (external reality) was investigated by a number of German researchers including Ernst Weber and Gustav Fechner. Their work was called **psychophysics**, and it introduced methods for measuring the relationship between physical stimuli and human perception that would serve as the basis for the new science of psychology (Fancher & Rutherford, 2011).

The formal development of modern psychology is usually credited to the work of German physician, physiologist, and philosopher Wilhelm Wundt (1832–1920). Wundt helped to establish the field of experimental psychology by serving as a strong promoter of the idea that psychology could be an experimental field and by providing classes, textbooks, and a laboratory for training students. In 1875, he joined the faculty at the University of Leipzig and quickly began to make plans for the creation of a program of experimental psychology. In 1879, he complemented his lectures on experimental psychology with a laboratory experience: an event that has served as the popular date for the establishment of the science of psychology.

Wilhelm Wundt is considered one of the founding figures of modern psychology. [CC0 Public Domain, https://goo.gl/m25gce]

The response to the new science was immediate and global. Wundt attracted students from around the world to study the new experimental psychology and work in his lab. Students were trained to offer detailed self-reports of their reactions to various stimuli, a procedure known as introspection. The goal was to identify the elements of consciousness. In addition to the study of sensation and perception, research was done on mental chronometry, more commonly known as reaction time. The work of Wundt and his students demonstrated that the mind could be measured and the nature of consciousness could be revealed through scientific means. It was an exciting proposition, and one that found great interest in America. After the opening of Wundt's lab in 1879, it took just four years for the first psychology laboratory to open in the United States (Benjamin, 2007).

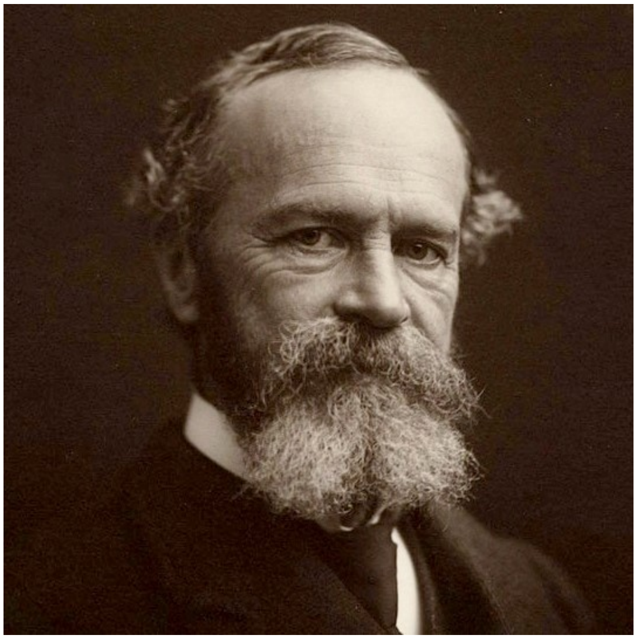
Scientific Psychology Comes to the United States

Wundt's version of psychology arrived in America most visibly through the work of Edward Bradford Titchener (1867–1927). A student of Wundt's, Titchener brought to America a brand of experimental psychology referred to as "structuralism." Structuralists were interested in the contents of the mind—what the mind is. For Titchener, the general adult mind was the proper focus for the new psychology, and he excluded from study those with mental deficiencies, children, and animals (Evans, 1972; Titchener, 1909).

Experimental psychology spread rather rapidly throughout North America. By 1900, there were more than 40 laboratories in the United States and Canada (Benjamin, 2000). Psychology in America also organized early with the establishment of the American Psychological Association (APA) in 1892. Titchener felt that this new organization did not adequately represent the interests of experimental psychology, so, in 1904, he organized a group of colleagues to create what is now known as the Society of Experimental Psychologists (Goodwin, 1985). The group met annually to discuss research in experimental psychology. Reflecting the times, women researchers were not invited (or welcome). It is interesting to note that Titchener's first doctoral student was a woman, Margaret Floy Washburn (1871–1939). Despite many barriers, in 1894, Washburn became the first woman in America to earn a Ph.D. in psychology and, in 1921, only the second woman to be elected president of the American Psychological Association (Scarborough & Furumoto, 1987).

Striking a balance between the science and practice of psychology continues to this day. In 1988, the American Psychological Society (now known as the Association for Psychological Science) was founded with the central mission of advancing psychological science.

Toward a Functional Psychology



William James was one of the leading figures in a new perspective on psychology called functionalism. [Image: Notman Studios, CC0 Public Domain, https://goo.gl/m25gce]

While Titchener and his followers adhered to a structural psychology, others in America were pursuing different approaches. William James, G. Stanley Hall, and James McKeen Cattell were among a group that became identified with "**functionalism**." Influenced by Darwin's evolutionary theory, functionalists were interested in the activities of the mind—what the mind does. An interest in functionalism opened the way for the study of a wide range of approaches, including animal and comparative psychology (Benjamin, 2007).

William James (1842–1910) is regarded as writing perhaps the most influential and important book in the field of psychology, *Principles of Psychology,* published in 1890. Opposed to the reductionist ideas of Titchener, James proposed that consciousness is ongoing and continuous; it cannot be isolated and reduced to elements. For James, consciousness helped us adapt to our environment in such ways as allowing us to make choices and have personal responsibility over those choices.

At Harvard, James occupied a position of authority and respect in psychology and philosophy. Through his teaching and writing, he influenced psychology for generations. One of his students, Mary Whiton Calkins (1863–1930), faced many of the challenges that confronted Margaret Floy Washburn and other women interested in pursuing graduate education in psychology. With much persistence, Calkins was able to study with James at Harvard. She eventually completed all the requirements for the doctoral degree, but Harvard refused to grant her a diploma because she was a woman. Despite these challenges, Calkins went on to become an accomplished researcher and the first woman elected president of the American Psychological Association in 1905 (Scarborough & Furumoto, 1987).

G. Stanley Hall (1844–1924) made substantial and lasting contributions to the establishment of psychology in the United States. At Johns Hopkins University, he founded the first psychological laboratory in America in 1883. In 1887, he created the first journal of psychology in America, *American Journal of Psychology*. In 1892, he founded the American Psychological Association (APA); in 1909, he invited and hosted Freud at Clark University (the only time Freud visited America). Influenced by evolutionary theory, Hall was interested in the process of adaptation and human development. Using surveys and questionnaires to study children, Hall wrote extensively on child development and education. While graduate education in psychology was restricted for women in Hall's time, it was all but non-existent for African Americans. In another first, Hall mentored Francis Cecil Sumner (1895–1954) who, in 1920, became the first African American to earn a Ph.D. in psychology in America (Guthrie, 2003).

James McKeen Cattell (1860–1944) received his Ph.D. with Wundt but quickly turned his interests to the assessment of **individual differences**. Influenced by the work of Darwin's cousin, Frances Galton, Cattell believed that mental abilities such as intelligence were inherited and could be measured using mental tests. Like Galton, he believed society was better served by identifying those with superior intelligence and supported efforts to encourage them to reproduce. Such beliefs were associated with **eugenics** (the promotion of selective breeding) and fueled early debates about the contributions of heredity and environment in defining who we are. At Columbia University, Cattell developed a department of psychology that became world famous also promoting psychological science through advocacy and as a publisher of scientific journals and reference works (Fancher, 1987; Sokal, 1980).

The Growth of Psychology

Throughout the first half of the 20th century, psychology continued to grow and flourish in America. It was large enough to accommodate varying points of view on the nature of mind and behavior. **Gestalt psychology** is a good example. The Gestalt movement began in Germany with the work of Max Wertheimer (1880–1943). Opposed to the reductionist approach of Wundt's laboratory psychology, Wertheimer and his colleagues Kurt Koffka (1886–1941), Wolfgang Kohler (1887–1967), and Kurt Lewin (1890–1947) believed that studying the whole of any experience was richer than studying individual aspects of that experience. The saying "the whole is greater than the sum of its parts" is a Gestalt perspective. Consider that a melody is an additional element beyond the collection of notes that comprise it. The Gestalt psychologists proposed that the mind often processes information simultaneously rather than sequentially. For instance, when you look at a photograph, you see a whole image, not just a collection of pixels of color. Using Gestalt principles, Wertheimer and his colleagues also explored the nature of learning and thinking. Most of the German Gestalt psychologists were Jewish and were forced to flee the Nazi regime due to the threats posed on both academic and personal freedoms. In America, they were able to introduce a new audience to the Gestalt perspective, demonstrating how it could be applied to perception and learning (Wertheimer, 1938). In many ways, the work of the Gestalt psychologists served as a precursor to the rise of **cognitive psychology** in America (Benjamin, 2007).

Behaviorism emerged early in the 20th century and became a major force in American psychology. Championed by psychologists such as John B. Watson (1878–1958) and B. F. Skinner (1904–1990), behaviorism rejected any reference to mind and viewed overt and observable behavior as the proper subject matter of psychology. Through the scientific study of behavior, it was hoped that laws of learning could be derived that would promote the prediction and control of behavior. Russian physiologist Ivan Pavlov (1849–1936) influenced early behaviorism in America. His work on conditioned learning, popularly referred to as classical conditioning, provided support for the notion that learning and behavior were controlled by events in the environment and could be explained with no reference to mind or consciousness (Fancher, 1987).

For decades, behaviorism dominated American psychology. By the 1960s, psychologists began to recognize that behaviorism was unable to fully explain human behavior because it neglected mental processes. The turn toward a cognitive psychology was not new. In the 1930s, British psychologist Frederic C. Bartlett (1886–1969) explored the idea of the constructive mind, recognizing that people use their past experiences to construct frameworks in which to understand new experiences. Some of the major pioneers in American cognitive psychology include Jerome Bruner (1915–), Roger Brown (1925–1997), and George Miller (1920–2012). In the 1950s, Bruner conducted pioneering studies on cognitive aspects of sensation and perception. Brown conducted original research on language and memory, coined the term "**flashbulb memory**," and figured out how to study the **tip-of-the-tongue phenomenon** (Benjamin, 2007). Miller's research on working memory is legendary. His 1956 paper "The Magic Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information"is one of the most highly cited papers in psychology. A popular interpretation of Miller's research was that the number of bits of information an average human can hold in **working memory** is 7 ± 2. Around the same time, the study of computer science was growing and was used as an analogy to explore and understand how the mind works. The work of Miller and others in the 1950s and 1960s has inspired tremendous interest in cognition and neuroscience, both of which dominate much of contemporary American psychology.

Applied Psychology in America

In America, there has always been an interest in the application of psychology to everyday life. Mental testing is an important example. Modern intelligence tests were developed by the French psychologist Alfred Binet (1857–1911). His goal was to develop a test that would identify schoolchildren in need of educational support. His test, which included tasks of reasoning and problem solving, was introduced in the United States by Henry Goddard (1866–1957) and later standardized by Lewis Terman (1877–1956) at Stanford University. The assessment and meaning of intelligence has fueled debates in American psychology and society for nearly 100 years. Much of this is captured in the nature-nurture debate that raises questions about the relative contributions of heredity and environment in determining intelligence (Fancher, 1987).

Applied psychology was not limited to mental testing. What psychologists were learning in their laboratories was applied in many settings including the military, business, industry, and education. The early 20th century was witness to rapid advances in applied psychology. Hugo Munsterberg (1863–1916) of Harvard University made contributions to such areas as employee selection, eyewitness testimony, and psychotherapy. Walter D. Scott (1869–1955) and Harry Hollingworth (1880–1956) produced original work on the psychology of advertising and marketing. Lillian Gilbreth (1878–1972) was a pioneer in industrial psychology and engineering psychology. Working with her husband, Frank, they promoted the use of time and motion studies to improve efficiency in industry. Lillian also brought the efficiency movement to the home, designing kitchens and appliances including the pop-up trashcan and refrigerator door shelving. Their psychology of efficiency also found plenty of applications at home with their 12 children. The experience served as the inspiration for the movie *Cheaper by the Dozen* (Benjamin, 2007).

Clinical psychology was also an early application of experimental psychology in America. Lightner Witmer (1867–1956) received his Ph.D. in experimental psychology with Wilhelm Wundt and returned to the University of Pennsylvania, where he opened a psychological clinic in 1896. Witmer believed that because psychology dealt with the study of sensation and perception, it should be of value in treating children with learning and behavioral problems. He is credited as the founder of both clinical and school psychology (Benjamin & Baker, 2004).

Although this is what most people see in their mind's eye when asked to envision a "psychologist" the APA recognizes as many as 58 different divisions of psychology. [Image: Bliusa, https://goo.gl/yrSUCr, CC BY-SA 4.0, https://goo.gl/6pvNbx]

Psychology as a Profession

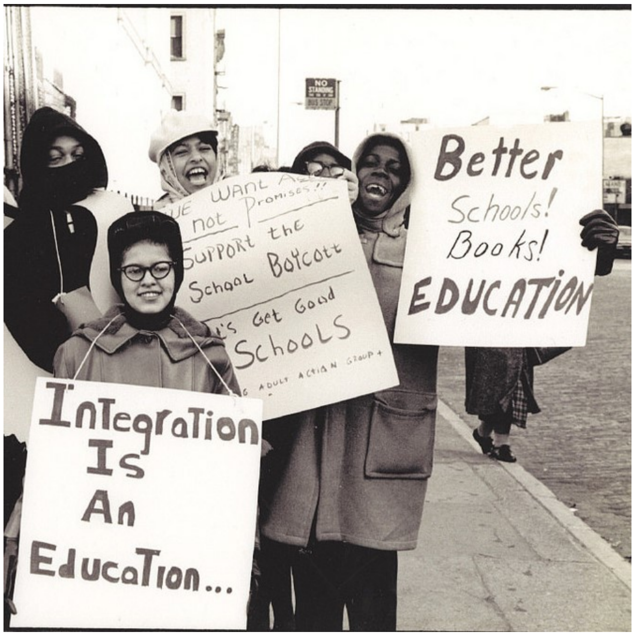
As the roles of psychologists and the needs of the public continued to change, it was necessary for psychology to begin to define itself as a profession. Without standards for training and practice, anyone could use the title psychologist and offer services to the public. As early as 1917, applied psychologists organized to create standards for education, training, and licensure. By the 1930s, these efforts led to the creation of the American Association for Applied Psychology (AAAP). While the American Psychological Association (APA) represented the interests of academic psychologists, AAAP served those in education, industry, consulting, and clinical work.

The advent of WWII changed everything. The psychiatric casualties of war were staggering, and there were simply not enough mental health professionals to meet the need. Recognizing the shortage, the federal government urged the AAAP and APA to work together to meet the mental health needs of the nation. The result was the merging of the AAAP and the APA and a focus on the training of professional psychologists. Through the provisions of National Mental Health Act of 1946, funding was made available that allowed the APA, the Veterans Administration, and the Public Health Service to work together to develop training programs that would produce clinical psychologists. These efforts led to the convening of the Boulder Conference on Graduate Education in Clinical Psychology in 1949 in Boulder, Colorado. The meeting launched doctoral training in psychology and gave us the **scientist-practitioner model** of training. Similar meetings also helped launch doctoral training programs in counseling and school psychology. Throughout the second half of the 20th century, alternatives to Boulder have been debated. In 1973, the Vail Conference on Professional Training in Psychology proposed the **scholar-practitioner model** and the Psy.D. degree (Doctor of Psychology). It is a training model that emphasizes clinical training and practice that has become more common (Cautin & Baker, in press).

Psychology and Society

Given that psychology deals with the human condition, it is not surprising that psychologists would involve themselves in social issues. For more than a century, psychology and psychologists have been agents of social action and change. Using the methods and tools of science, psychologists have challenged assumptions, stereotypes, and stigma. Founded in 1936, the Society for the Psychological Study of Social Issues (SPSSI) has supported research and action on a wide range of social issues. Individually, there have been many psychologists whose efforts have promoted social change. Helen Thompson Woolley (1874–1947) and Leta S. Hollingworth (1886–1939) were pioneers in research on the psychology of sex differences. Working in the early 20th century, when women's rights were marginalized, Thompson examined the assumption that women were overemotional compared to men and found that emotion did not influence women's decisions any more than it did men's. Hollingworth found that menstruation did not negatively impact women's cognitive or motor abilities. Such work combatted harmful stereotypes and showed that psychological research could contribute to social change (Scarborough & Furumoto, 1987).

Among the first generation of African American psychologists, Mamie Phipps Clark (1917–1983) and her husband Kenneth Clark (1914–2005) studied the psychology of race and demonstrated the ways in which school segregation negatively impacted the self-esteem of African American children. Their research was influential in the 1954 Supreme Court ruling in the case of *Brown v. Board of Education,* which ended school segregation (Guthrie, 2003). In psychology, greater advocacy for issues impacting the African American community were advanced by the creation of the Association of Black Psychologists (ABPsi) in 1968.


NO STANDING BUS STOP
not Promises!!
Support the School Boycott
Get Good Schools
Better Schools! Books! EDUCATION
Integration Is An Education...

Mamie Phipps Clark and Kenneth Clark studied the negative impacts of segregated education on African-American children. [Image: Penn State Special Collection, https://goo.gl/WP7Dgc, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

In 1957, psychologist Evelyn Hooker (1907–1996) published the paper "The Adjustment of the Male Overt Homosexual," reporting on her research that showed no significant differences in psychological adjustment between homosexual and heterosexual men. Her research helped to de-pathologize homosexuality and contributed to the decision by the American Psychiatric Association to remove homosexuality from the Diagnostic and Statistical Manual of Mental Disorders in 1973 (Garnets & Kimmel, 2003).

Conclusion

Growth and expansion have been a constant in American psychology. In the latter part of the 20th century, areas such as social, developmental, and personality psychology made major contributions to our understanding of what it means to be human. Today neuroscience is enjoying tremendous interest and growth.

As mentioned at the beginning of the module, it is a challenge to cover all the history of psychology in such a short space. Errors of omission and commission are likely in such a selective review. The history of psychology helps to set a stage upon which the story of psychology can be told. This brief summary provides some glimpse into the depth and rich content offered by the history of psychology. The learning modules in the Noba psychology collection are all elaborations on the foundation created by our shared past. It is hoped that you will be able to see these connections and have a greater understanding and appreciation for both the unity and diversity of the field of psychology.

Timeline

1600s – Rise of empiricism emphasizing centrality of human observer in acquiring knowledge

1850s - Helmholz measures neural impulse / Psychophysics studied by Weber & Fechner

1859 - Publication of Darwin's *Origin of Species*

1879 - Wundt opens lab for experimental psychology

1883 - First psychology lab opens in the United States

1887 – First American psychology journal is published: *American Journal of Psychology*

1890 – James publishes *Principles of Psychology*

1892 – APA established

1894 – Margaret Floy Washburn is first U.S. woman to earn Ph.D. in psychology

1904 - Founding of Titchener's experimentalists

1905 - Mary Whiton Calkins is first woman president of APA

1909 – Freud’s only visit to the United States

1913 - John Watson calls for a psychology of behavior

1920 – Francis Cecil Sumner is first African American to earn Ph.D. in psychology

1921 – Margaret Floy Washburn is second woman president of APA

1930s – Creation and growth of the American Association for Applied Psychology (AAAP) / Gestalt psychology comes to America

1936- Founding of The Society for the Psychological Study of Social Issues

1940s – Behaviorism dominates American psychology

1946 – National Mental Health Act

1949 – Boulder Conference on Graduate Education in Clinical Psychology

1950s – Cognitive psychology gains popularity

1954 – *Brown v. Board of Education*

1957 – Evelyn Hooker publishes T*he Adjustment of the Male Overt Homosexual*

1968 – Founding of the Association of Black Psychologists

1973 – Psy.D. proposed at the Vail Conference on Professional Training in Psychology

1988 – Founding of the American Psychological Society (now known as the Association for Psychological Science)

Outside Resources

Podcast: History of Psychology Podcast Series
http://www.yorku.ca/christo/podcasts/

Web: Advances in the History of Psychology
http://ahp.apps01.yorku.ca/

Web: Center for the History of Psychology
http://www.uakron.edu/chp

Web: Classics in the History of Psychology
http://psychclassics.yorku.ca/

Web: Psychology's Feminist Voices
http://www.feministvoices.com/

Web: This Week in the History of Psychology
http://www.yorku.ca/christo/podcasts/

Discussion Questions

1. Why was psychophysics important to the development of psychology as a science?
2. How have psychologists participated in the advancement of social issues?
3. Name some ways in which psychology began to be applied to the general public and everyday problems.
4. Describe functionalism and structuralism and their influences on behaviorism and cognitive psychology.

Vocabulary

Behaviorism
The study of behavior.

Cognitive psychology
The study of mental processes.

Consciousness
Awareness of ourselves and our environment.

Empiricism
The belief that knowledge comes from experience.

Eugenics
The practice of selective breeding to promote desired traits.

Flashbulb memory
A highly detailed and vivid memory of an emotionally significant event.

Functionalism
A school of American psychology that focused on the utility of consciousness.

Gestalt psychology
An attempt to study the unity of experience.

Individual differences
Ways in which people differ in terms of their behavior, emotion, cognition, and development.

Introspection
A method of focusing on internal processes.

Neural impulse
An electro-chemical signal that enables neurons to communicate.

Practitioner-Scholar Model
A model of training of professional psychologists that emphasizes clinical practice.

Psychophysics
Study of the relationships between physical stimuli and the perception of those stimuli.

Realism
A point of view that emphasizes the importance of the senses in providing knowledge of the external world.

Scientist-practitioner model
A model of training of professional psychologists that emphasizes the development of both research and clinical skills.

Structuralism
A school of American psychology that sought to describe the elements of conscious experience.

Tip-of-the-tongue phenomenon
The inability to pull a word from memory even though there is the sensation that that word is available.

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2

The Brain

Diane Beck & Evelina Tapia

The human brain is responsible for all behaviors, thoughts, and experiences described in this textbook. This module provides an introductory overview of the brain, including some basic neuroanatomy, and brief descriptions of the neuroscience methods used to study it.

Learning Objectives

- Name and describe the basic function of the brain stem, cerebellum, and cerebral hemispheres.
- Name and describe the basic function of the four cerebral lobes: occipital, temporal, parietal, and frontal cortex.
- Describe a split-brain patient and at least two important aspects of brain function that these patients reveal.
- Distinguish between gray and white matter of the cerebral hemispheres.
- Name and describe the most common approaches to studying the human brain.
- Distinguish among four neuroimaging methods: PET, fMRI, EEG, and DOI.
- Describe the difference between spatial and temporal resolution with regard to brain function.

Introduction

Any textbook on psychology would be incomplete without reference to the brain. Every behavior, thought, or experience described in the other modules must be implemented in the brain. A detailed understanding of the human brain can help us make sense of human experience and behavior. For example, one well-established fact about human cognition is that it is limited. We cannot do two complex tasks at once: We cannot read and carry on a conversation at the same time, text and drive, or surf the Internet while listening to a lecture, at least not successfully or safely. We cannot even pat our head and rub our stomach at the same time (with exceptions, see “A Brain Divided”). Why is this? Many people have suggested that such limitations reflect the fact that the behaviors draw on the same resource; if one behavior uses up most of the resource there is not enough resource left for the other. But what might this limited resource be in the brain?

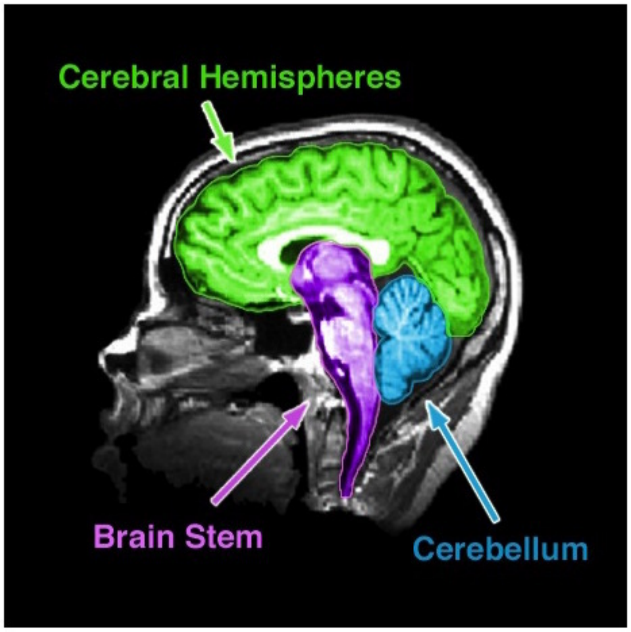


Figure 1. An MRI of the human brain delineating three major structures: the cerebral hemispheres, brain stem, and cerebellum.

The brain uses oxygen and glucose, delivered via the blood. The brain is a large consumer of these metabolites, using 20% of the oxygen and calories we consume despite being only 2% of our total weight. However, as long as we are not oxygen-deprived or malnourished, we have more than enough oxygen and glucose to fuel the brain. Thus, insufficient “brain fuel” cannot explain our limited capacity. Nor is it likely that our limitations reflect too few neurons. The average human brain contains 100 billion neurons. It is also not the case that we use only 10% of our brain, a myth that was likely started to imply we had untapped potential. Modern neuroimaging (see “Studying the Human Brain”) has shown that we use all parts of brain, just at different times, and certainly more than 10% at any one time.

If we have an abundance of brain fuel and neurons, how can we explain our limited cognitive abilities? Why can’t we do more at once? The most likely explanation is the way these neurons are wired up. We know, for instance, that many neurons in the visual cortex (the part of the brain responsible for processing visual information) are hooked up in such a way as to inhibit each other (Beck & Kastner, 2009). When one neuron fires, it suppresses the firing of other nearby neurons. If two neurons that are hooked up in an inhibitory way both fire, then neither neuron can fire as vigorously as it would otherwise. This competitive behavior among neurons limits how much visual information the brain can respond to at the same time. Similar kinds of competitive wiring among neurons may underlie many of our limitations. Thus, although talking about limited resources provides an intuitive description of our limited capacity behavior, a detailed understanding of the brain suggests that our limitations more likely reflect the complex way in which neurons talk to each other rather than the depletion of any specific resource.

The Anatomy of the Brain

There are many ways to subdivide the mammalian brain, resulting in some inconsistent and ambiguous nomenclature over the history of neuroanatomy (Swanson, 2000). For simplicity, we will divide the brain into three basic parts: the brain stem, cerebellum, and cerebral hemispheres (see Figure 1). In Figure 2, however, we depict other prominent groupings (Swanson, 2000) of the six major subdivisions of the brain (Kandal, Schwartz, & Jessell, 2000).

Brain Stem

The brain stem is sometimes referred to as the "trunk" of the brain. It is responsible for many of the neural functions that keep us alive, including regulating our respiration (breathing), heart rate, and digestion. In keeping with its function, if a patient sustains severe damage to the brain stem he or she will require "life support" (i.e., machines are used to keep him or her alive). Because of its vital role in survival, in many countries a person who has lost brain stem function is said to be "brain dead," although other countries require significant tissue loss in the cortex (of the cerebral hemispheres), which is responsible for our conscious experience, for the same diagnosis. The brain stem includes the medulla, pons, midbrain, and diencephalon (which consists of thalamus and hypothalamus). Collectively, these regions also are involved in our sleep–wake cycle, some sensory and motor function, as well as growth and other hormonal behaviors.

Cerebellum

The cerebellum is the distinctive structure at the back of the brain. The Greek philosopher and scientist Aristotle aptly referred to it as the "small brain" ("parencephalon" in Greek, "cerebellum" in Latin) in order to distinguish it from the "large brain" ("encephalon" in Greek, "cerebrum" in Latin). The cerebellum is critical for coordinated movement and posture. More recently, neuroimaging studies (see "Studying the Human Brain") have implicated it in a range of cognitive abilities, including language. It is perhaps not surprising that the cerebellum's

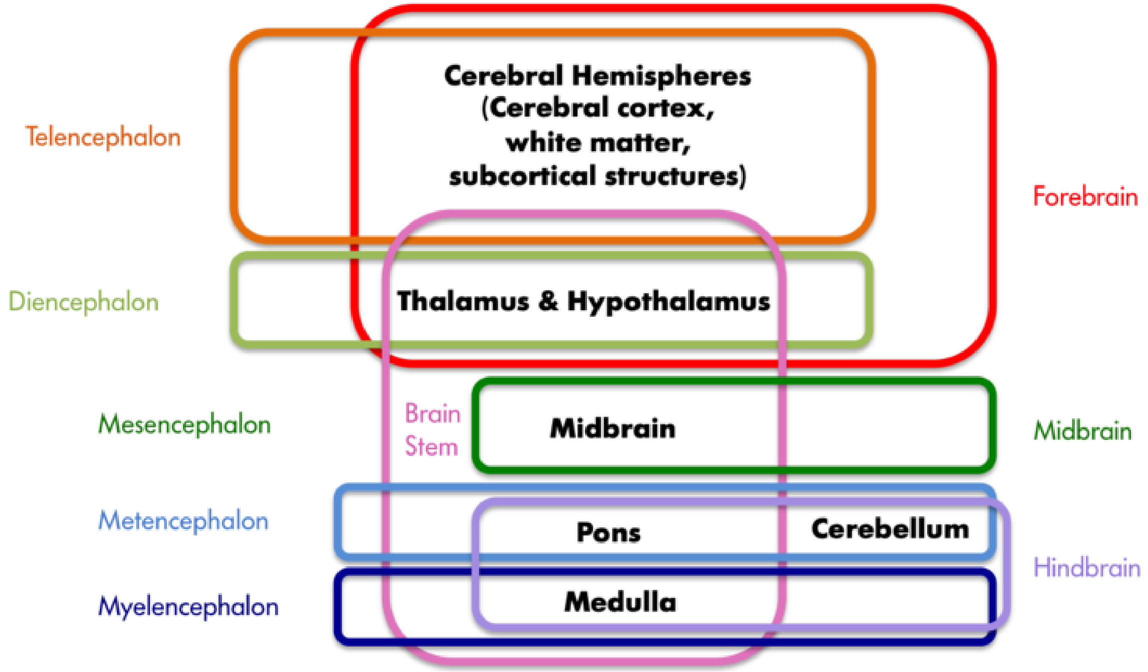


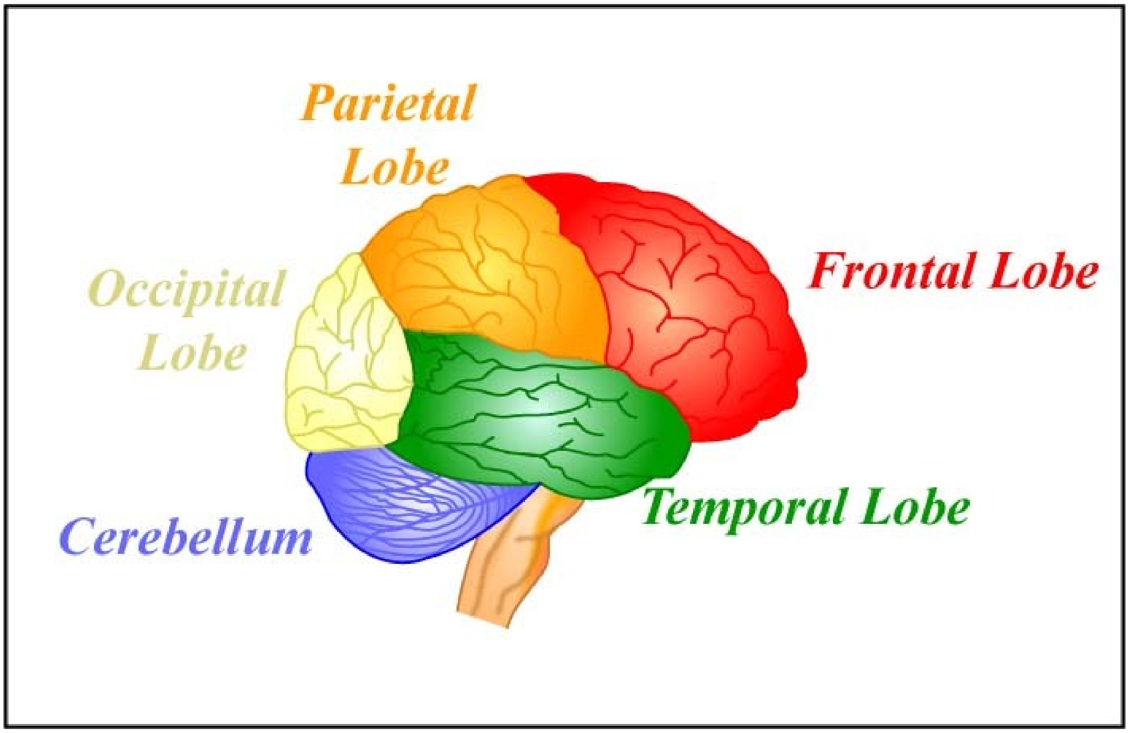
Figure 2. A sample of neuroanatomy nomenclature. The colored boxes indicate the different groupings of the seven structures printed in black, with the labels matching the color of the boxes. The hindbrain, midbrain, and forebrain nomenclature stems from the development of the vertebrate brain; these three areas differentiate early in embryonic development and later give rise to the structures listed in black. These three areas further subdivide into the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon at a later stage of development.

influence extends beyond that of movement and posture, given that it contains the greatest number of neurons of any structure in the brain. However, the exact role it plays in these higher functions is still a matter of further study.

Cerebral Hemispheres

The cerebral hemispheres are responsible for our cognitive abilities and conscious experience. They consist of the cerebral cortex and accompanying white matter ("cerebrum" in Latin) as well as the subcortical structures of the basal ganglia, amygdala, and hippocampal formation. The cerebral cortex is the largest and most visible part of the brain, retaining the Latin name (cerebrum) for "large brain" that Aristotle coined. It consists of two hemispheres (literally two half spheres) and gives the brain its characteristic gray and convoluted appearance; the folds and grooves of the cortex are called gyri and sulci (gyrus and sulcus if referring to just one), respectively.

The two cerebral hemispheres can be further subdivided into four lobes: the occipital, temporal, parietal, and frontal lobes. The occipital lobe is responsible for vision, as is much



The four lobes of the brain and the cerebellum. [Image: MIT OpenCourseWare, https://goo.gl/RwUEVt, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

of the temporal lobe. The temporal lobe is also involved in auditory processing, memory, and multisensory integration (e.g., the convergence of vision and audition). The parietal lobe houses the somatosensory (body sensations) cortex and structures involved in visual attention, as well as multisensory convergence zones. The frontal lobe houses the motor cortex and structures involved in motor planning, language, judgment, and decision-making. Not surprisingly then, the frontal lobe is proportionally larger in humans than in any other animal.

The subcortical structures are so named because they reside beneath the cortex. The basal ganglia are critical to voluntary movement and as such make contact with the cortex, the thalamus, and the brain stem. The amygdala and hippocampal formation are part of the limbic system, which also includes some cortical structures. The limbic system plays an important role in emotion and, in particular, in aversion and gratification.

A Brain Divided

The two cerebral hemispheres are connected by a dense bundle of white matter tracts called the corpus callosum. Some functions are replicated in the two hemispheres. For example, both hemispheres are responsible for sensory and motor function, although the sensory and motor cortices have a **contralateral** (or opposite-side) representation; that is, the left cerebral hemisphere is responsible for movements and sensations on the right side of the body and the right cerebral hemisphere is responsible for movements and sensations on the left side of the body. Other functions are **lateralized**; that is, they reside primarily in one hemisphere or the other. For example, for right-handed and the majority of left-handed individuals, the left hemisphere is most responsible for language.

There are some people whose two hemispheres are not connected, either because the corpus callosum was surgically severed (**callosotomy**) or due to a genetic abnormality. These **split-brain patients** have helped us understand the functioning of the two hemispheres. First, because of the contralateral representation of sensory information, if an object is placed in only the left or only the right **visual hemifield**, then only the right or left hemisphere, respectively, of the split-brain patient will see it. In essence, it is as though the person has two brains in his or her head, each seeing half the world. Interestingly, because language is very often localized in the left hemisphere, if we show the right hemisphere a picture and ask the patient what she saw, she will say she didn't see anything (because only the left hemisphere can speak and it didn't see anything). However, we know that the right hemisphere sees the picture because if the patient is asked to press a button whenever she sees the image, the left hand (which is controlled by the right hemisphere) will respond despite the left hemisphere's denial that anything was there. There are also some advantages to having disconnected hemispheres. Unlike those with a fully functional corpus callosum, a split-brain patient can simultaneously search for something in his right and left visual fields (Luck, Hillyard, Mangun, & Gazzaniga, 1989) and can do the equivalent of rubbing his stomach and patting his head at the same time (Franz, Eliason, Ivry, & Gazzaniga, 1996). In other words, they exhibit less competition between the hemispheres.

Gray Versus White Matter

The cerebral hemispheres contain both grey and white matter, so called because they appear grayish and whitish in dissections or in an MRI (magnetic resonance imaging; see, "Studying the Human Brain"). The **gray matter** is composed of the neuronal cell bodies (see module, "Neurons"). The cell bodies (or soma) contain the genes of the cell and are responsible for metabolism (keeping the cell alive) and synthesizing proteins. In this way, the cell body is the workhorse of the cell. The **white matter** is composed of the axons of the neurons, and, in particular, axons that are covered with a sheath of **myelin** (fatty support cells that are whitish in color). Axons conduct the electrical signals from the cell and are, therefore, critical to cell communication. People use the expression “use your gray matter” when they want a person to think harder. The “gray matter” in this expression is probably a reference to the cerebral hemispheres more generally; the gray cortical sheet (the convoluted surface of the cortex) being the most visible. However, both the gray matter and white matter are critical to proper functioning of the mind. Losses of either result in deficits in language, memory, reasoning, and other mental functions. See Figure 3 for MRI slices showing both the inner white matter that connects the cell bodies in the gray cortical sheet.

Studying the Human Brain

How do we know what the brain does? We have gathered knowledge about the functions of the brain from many different methods. Each method is useful for answering distinct types of questions, but the strongest evidence for a specific role or function of a particular brain area is converging evidence; that is, similar findings reported from multiple studies using different methods.

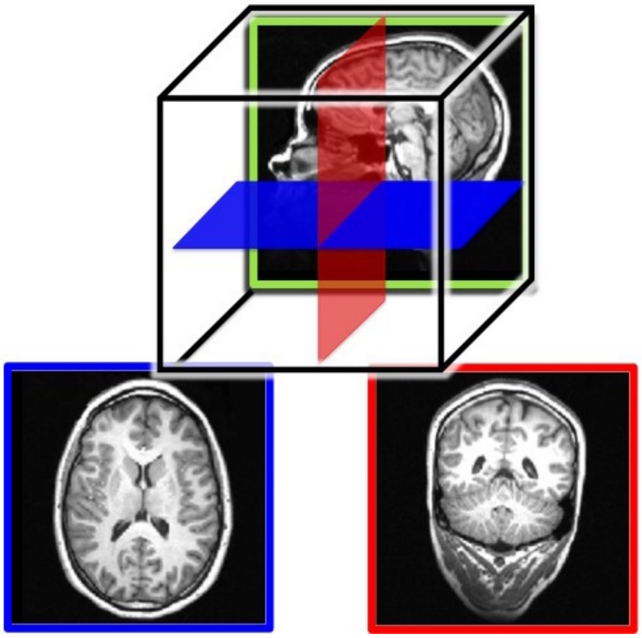


Figure 3. MRI slices of the human brain. Both the outer gray matter and inner white matter are visible in each image. The brain is a three-dimensional (3-D) structure, but an image is two-dimensional (2-D). Here, we show example slices of the three possible 2-D cuts through the brain: a saggital slice (top image), a horizontal slice (bottom left), which is also know as a transverse or axial slice, and a coronal slice (bottom right). The bottom two images are color coded to match the illustration of the relative orientations of the three slices in the top image.

One of the first organized attempts to study the functions of the brain was phrenology, a popular field of study in the first half of the 19th century. Phrenologists assumed that various features of the brain, such as its uneven surface, are reflected on the skull; therefore, they attempted to correlate bumps and indentations of the skull with specific functions of the brain. For example, they would claim that a very artistic person has ridges on the head that vary in size and location from those of someone who is very good at spatial reasoning. Although the assumption that the skull reflects the underlying brain structure has been proven wrong, phrenology nonetheless significantly impacted current-day neuroscience and its thinking about the functions of the brain. That is, different parts of the brain are devoted to very specific functions that can be identified through scientific inquiry.

Neuroanatomy

Dissection of the brain, in either animals or cadavers, has been a critical tool of neuroscientists since 340 BC when Aristotle first published his dissections. Since then this method has advanced considerably with the discovery of various staining techniques that can highlight particular cells. Because the brain can be sliced very thinly, examined under the microscope, and particular cells highlighted, this method is especially useful for studying specific groups of neurons or small brain structures; that is, it has a very high spatial resolution. Dissections allow scientists to study changes in the brain that occur due to various diseases or experiences (e.g., exposure to drugs or brain injuries).

Virtual dissection studies with living humans are also conducted. Here, the brain is imaged using computerized axial tomography (CAT) or MRI scanners; they reveal with very high precision the various structures in the brain and can help detect changes in gray or white matter. These changes in the brain can then be correlated with behavior, such as performance on memory tests, and, therefore, implicate specific brain areas in certain cognitive functions.

Changing the Brain

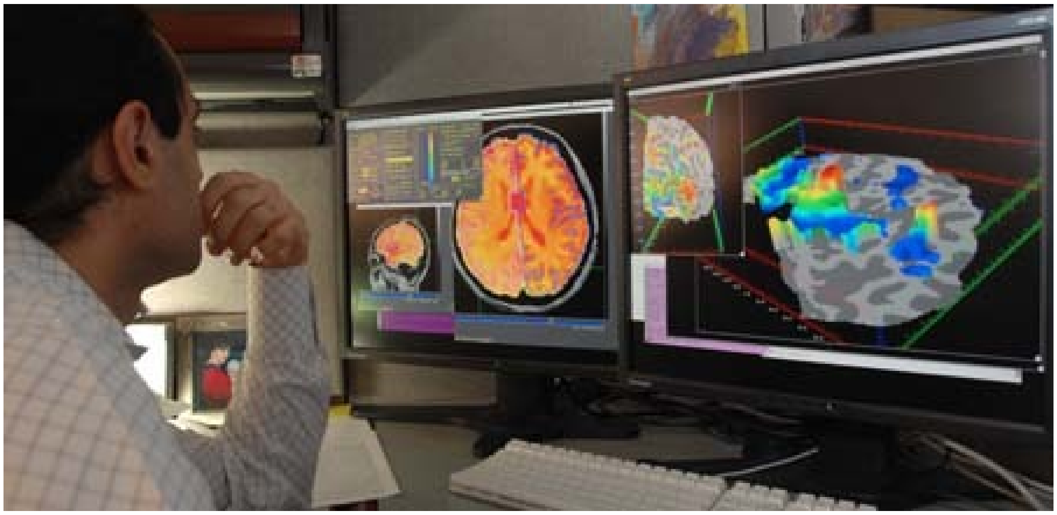
Some researchers induce lesions or ablate (i.e., remove) parts of the brain in animals. If the animal's behavior changes after the lesion, we can infer that the removed structure is important for that behavior. Lesions of human brains are studied in patient populations only; that is, patients who have lost a brain region due to a stroke or other injury, or who have had surgical removal of a structure to treat a particular disease (e.g., a callosotomy to control epilepsy, as in split-brain patients). From such case studies, we can infer brain function by measuring changes in the behavior of the patients before and after the lesion.

Because the brain works by generating electrical signals, it is also possible to change brain function with electrical stimulation. Transcranial magnetic stimulation (TMS) refers to a technique whereby a brief magnetic pulse is applied to the head that temporarily induces a weak electrical current in the brain. Although effects of TMS are sometimes referred to as temporary virtual lesions, it is more appropriate to describe the induced electricity as interference with neurons' normal communication with each other. TMS allows very precise study of when events in the brain happen so it has a good temporal resolution, but its application is limited only to the surface of the cortex and cannot extend to deep areas of the brain.

Transcranial direct current stimulation (tDCS) is similar to TMS except that it uses electrical current directly, rather than inducing it with magnetic pulses, by placing small electrodes on the skull. A brain area is stimulated by a low current (equivalent to an AA battery) for a more extended period of time than TMS. When used in combination with cognitive training, tDCS has been shown to improve performance of many cognitive functions such as mathematical ability, memory, attention, and coordination (e.g., Brasil-Neto, 2012; Feng, Bowden, & Kautz, 2013; Kuo & Nitsche, 2012).

Neuroimaging

Neuroimaging tools are used to study the brain in action; that is, when it is engaged in a specific task. Positron emission tomography (PET) records blood flow in the brain. The PET scanner detects the radioactive substance that is injected into the bloodstream of the participant just before or while he or she is performing some task (e.g., adding numbers). Because active neuron populations require metabolites, more blood and hence more radioactive substance flows into those regions. PET scanners detect the injected radioactive substance in specific brain regions, allowing researchers to infer that those areas were active during the task. Functional magnetic resonance imaging (fMRI) also relies on blood flow in the brain. This method, however, measures the changes in oxygen levels in the blood and does not require any substance to be injected into the participant. Both of these tools have good spatial resolution (although not as precise as dissection studies), but because it takes at least several seconds for the blood to arrive to the active areas of the brain, PET and fMRI have poor temporal resolution; that is, they do not tell us very precisely when the activity



A researcher looking at the areas of activation in the brain of a study participant who had an fMRI scan – areas of brain activation are determined by the amount of blood flow to a certain area – the more blood flow, the higher the activation of that area of the brain. [Image: National Institute of Mental Health, CC0 Public Domain, https://goo.gl/m25gce] occurred.

Electroencephalography (EEG), on the other hand, measures the electrical activity of the brain, and therefore, it has a much greater temporal resolution (millisecond precision rather than seconds) than PET or fMRI. Like tDCS, electrodes are placed on the participant's head when he or she is performing a task. In this case, however, many more electrodes are used, and they measure rather than produce activity. Because the electrical activity picked up at any particular electrode can be coming from anywhere in the brain, EEG has poor spatial resolution; that is, we have only a rough idea of which part of the brain generates the measured activity.

Diffuse optical imaging (DOI) can give researchers the best of both worlds: high spatial and temporal resolution, depending on how it is used. Here, one shines infrared light into the brain, and measures the light that comes back out. DOI relies on the fact that the properties of the light change when it passes through oxygenated blood, or when it encounters active neurons. Researchers can then infer from the properties of the collected light what regions in the brain were engaged by the task. When DOI is set up to detect changes in blood oxygen levels, the temporal resolution is low and comparable to PET or fMRI. However, when DOI is set up to directly detect active neurons, it has both high spatial and temporal resolution.

Because the spatial and temporal resolution of each tool varies, strongest evidence for what role a certain brain area serves comes from converging evidence. For example, we are more likely to believe that the hippocampal formation is involved in memory if multiple studies using a variety of tasks and different neuroimaging tools provide evidence for this hypothesis. The brain is a complex system, and only advances in brain research will show whether the brain can ever really understand itself.

Outside Resources

Video: Brain Bank at Harvard (National Geographic video)
http://video.nationalgeographic.com/video/science/health-human-body-sci/human-body/brain-bank-sci/

Video: Videos of a split-brain patient
http://youtu.be/ZMLzP1VCANo

Web: Atlas of the Human Brain: interactive demos and brain sections
http://www.thehumanbrain.info/

Web: Harvard University Human Brain Atlas: normal and diseased brain scans
http://www.med.harvard.edu/aanlib/home.html

Discussion Questions

1. In what ways does the segmentation of the brain into the brain stem, cerebellum, and cerebral hemispheres provide a natural division?
2. How has the study of split-brain patients been informative?
3. What is behind the expression “use your gray matter,” and why is it not entirely accurate?
4. Why is converging evidence the best kind of evidence in the study of brain function?
5. If you were interested in whether a particular brain area was involved in a specific behavior, what neuroscience methods could you use?
6. If you were interested in the precise time in which a particular brain process occurred, which neuroscience methods could you use?

Vocabulary

Ablation
Surgical removal of brain tissue.

Axial plane
See “horizontal plane.”

Basal ganglia
Subcortical structures of the cerebral hemispheres involved in voluntary movement.

Brain stem
The “trunk” of the brain comprised of the medulla, pons, midbrain, and diencephalon.

Callosotomy
Surgical procedure in which the corpus callosum is severed (used to control severe epilepsy).

Case study
A thorough study of a patient (or a few patients) with naturally occurring lesions.

Cerebellum
The distinctive structure at the back of the brain, Latin for “small brain.”

Cerebral cortex
The outermost gray matter of the cerebrum; the distinctive convolutions characteristic of the mammalian brain.

Cerebral hemispheres
The cerebral cortex, underlying white matter, and subcortical structures.

Cerebrum
Usually refers to the cerebral cortex and associated white matter, but in some texts includes the subcortical structures.

Contralateral
Literally “opposite side”; used to refer to the fact that the two hemispheres of the brain process sensory information and motor commands for the opposite side of the body (e.g., the left hemisphere controls the right side of the body).

Converging evidence
Similar findings reported from multiple studies using different methods.

Coronal plane
A slice that runs from head to foot; brain slices in this plane are similar to slices of a loaf of bread, with the eyes being the front of the loaf.

Diffuse optical imaging (DOI)
A neuroimaging technique that infers brain activity by measuring changes in light as it is passed through the skull and surface of the brain.

Electroencephalography (EEG)
A neuroimaging technique that measures electrical brain activity via multiple electrodes on the scalp.

Frontal lobe
The front most (anterior) part of the cerebrum; anterior to the central sulcus and responsible for motor output and planning, language, judgment, and decision-making.

Functional magnetic resonance imaging (fMRI)
Functional magnetic resonance imaging (fMRI): A neuroimaging technique that infers brain activity by measuring changes in oxygen levels in the blood.

Gray matter
The outer grayish regions of the brain comprised of the neurons’ cell bodies.

Gyri
(plural) Folds between sulci in the cortex.

Gyrus
A fold between sulci in the cortex.

Horizontal plane
A slice that runs horizontally through a standing person (i.e., parallel to the floor); slices of brain in this plane divide the top and bottom parts of the brain; this plane is similar to slicing a hamburger bun.

Lateralized
To the side; used to refer to the fact that specific functions may reside primarily in one

hemisphere or the other (e.g., for the majority individuals, the left hemisphere is most responsible for language).

Lesion
A region in the brain that suffered damage through injury, disease, or medical intervention.

Limbic system
Includes the subcortical structures of the amygdala and hippocampal formation as well as some cortical structures; responsible for aversion and gratification.

Metabolite
A substance necessary for a living organism to maintain life.

Motor cortex
Region of the frontal lobe responsible for voluntary movement; the motor cortex has a contralateral representation of the human body.

Myelin
Fatty tissue, produced by glial cells (see module, “Neurons”) that insulates the axons of the neurons; myelin is necessary for normal conduction of electrical impulses among neurons.

Nomenclature
Naming conventions.

Occipital lobe
The back most (posterior) part of the cerebrum; involved in vision.

Parietal lobe
The part of the cerebrum between the frontal and occipital lobes; involved in bodily sensations, visual attention, and integrating the senses.

Phrenology
A now-discredited field of brain study, popular in the first half of the 19th century that correlated bumps and indentations of the skull with specific functions of the brain.

Positron emission tomography (PET)
A neuroimaging technique that measures brain activity by detecting the presence of a radioactive substance in the brain that is initially injected into the bloodstream and then pulled in by active brain tissue.

Sagittal plane
A slice that runs vertically from front to back; slices of brain in this plane divide the left and right side of the brain; this plane is similar to slicing a baked potato lengthwise.

Somatosensory (body sensations) cortex
The region of the parietal lobe responsible for bodily sensations; the somatosensory cortex has a contralateral representation of the human body.

Spatial resolution
A term that refers to how small the elements of an image are; high spatial resolution means the device or technique can resolve very small elements; in neuroscience it describes how small of a structure in the brain can be imaged.

Split-brain patient
A patient who has had most or all of his or her corpus callosum severed.

Subcortical
Structures that lie beneath the cerebral cortex, but above the brain stem.

Sulci
(plural) Grooves separating folds of the cortex.

Sulcus
A groove separating folds of the cortex.

Temporal lobe
The part of the cerebrum in front of (anterior to) the occipital lobe and below the lateral fissure; involved in vision, auditory processing, memory, and integrating vision and audition.

Temporal resolution
A term that refers to how small a unit of time can be measured; high temporal resolution means capable of resolving very small units of time; in neuroscience it describes how precisely in time a process can be measured in the brain.

Transcranial direct current stimulation (tDCS)
A neuroscience technique that passes mild electrical current directly through a brain area by placing small electrodes on the skull.

Transcranial magnetic stimulation (TMS)

A neuroscience technique whereby a brief magnetic pulse is applied to the head that temporarily induces a weak electrical current that interferes with ongoing activity.

Transverse plane
See “horizontal plane.”

Visual hemifield
The half of visual space (what we see) on one side of fixation (where we are looking); the left hemisphere is responsible for the right visual hemifield, and the right hemisphere is responsible for the left visual hemifield.

White matter
The inner whitish regions of the cerebrum comprised of the myelinated axons of neurons in the cerebral cortex.

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3

Sensation and Perception

Adam John Privitera

The topics of sensation and perception are among the oldest and most important in all of psychology. People are equipped with senses such as sight, hearing and taste that help us to take in the world around us. Amazingly, our senses have the ability to convert real-world information into electrical information that can be processed by the brain. The way we interpret this information-- our perceptions-- is what leads to our experiences of the world. In this module, you will learn about the biological processes of sensation and how these can be combined to create perceptions.

Learning Objectives

- Differentiate the processes of sensation and perception.
- Explain the basic principles of sensation and perception.
- Describe the function of each of our senses.
- Outline the anatomy of the sense organs and their projections to the nervous system.
- Apply knowledge of sensation and perception to real world examples.
- Explain the consequences of multimodal perception.

Introduction

"Once I was hiking at Cape Lookout State Park in Tillamook, Oregon. After passing through a vibrantly colored, pleasantly scented, temperate rainforest, I arrived at a cliff overlooking the Pacific Ocean.

I grabbed the cold metal railing near the edge and looked out at the sea. Below me, I could see a pod of sea lions swimming in the deep blue water. All around me I could smell the salt from the sea and the scent of wet, fallen leaves."

This description of a single memory highlights the way a person's senses are so important to our experience of the world around us.

Our senses combine to create our perceptions of the world. [Image: Adam John Privitera, CC BY-NC-SA 4.0, https://goo.gl/H2QaA8]

Before discussing each of our extraordinary senses individually, it is necessary to cover some basic concepts that apply to all of them. It is probably best to start with one very important distinction that can often be confusing: the difference between sensation and perception. The *physical* process during which our sensory organs—those involved with hearing and taste, for example—respond to external stimuli is called **sensation**. Sensation happens when you eat noodles or feel the wind on your face or hear a car horn honking in the distance. During sensation, our sense organs are engaging in **transduction**, the conversion of one form of energy into another. Physical energy such as light or a sound wave is converted into a form of energy the brain can understand: electrical stimulation. After our brain receives the electrical signals, we make sense of all this stimulation and begin to appreciate the complex world around us. This *psychological* process—making sense of the stimuli—is called **perception**. It is during this process that you are able to *identify* a gas leak in your home or a song that reminds you of a specific afternoon spent with friends.

Regardless of whether we are talking about sight or taste or any of the individual senses, there are a number of basic principles that influence the way our sense organs work. The first of these influences is our ability to detect an external stimulus. Each sense organ—our eyes or tongue, for instance—requires a minimal amount of stimulation in order to detect a stimulus. This **absolute threshold** explains why you don't smell the perfume someone is wearing in a classroom unless they are somewhat close to you. Because absolute threshold changes throughout the day and based on what other stimuli you have recently experienced, researchers define absolute threshold as the minimum about of stimulation needed to detect a stimulus 50% of the time.

The way we measure absolute thresholds is by using a method called **signal detection**. This process involves presenting stimuli of varying intensities to a research participant in order to determine the level at which he or she can reliably detect stimulation in a given sense. During one type of hearing test, for example, a person listens to increasingly louder tones (starting from silence). This type of test is called *the method of limits*, and it is an effort to determine the point, or threshold, at which a person begins to hear a stimulus (see Additional Resources for a video demonstration). In the example of louder tones, the method of limits test is using *ascending trials*. Some method of limits tests use *descending trials*, such as making a light grow dimmer until a person can no longer see it. Correctly indicating that a sound was heard is called a hit; failing to do so is called a miss. Additionally, indicating that a sound was heard when one wasn't played is called a *false alarm*, and correctly identifying when a sound wasn't played is a *correct rejection*.

Through these and other studies, we have been able to gain an understanding of just how remarkable our senses are. For example, the human eye is capable of detecting candlelight from 30 miles away in the dark. We are also capable of hearing the ticking of a watch in a quiet environment from 20 feet away. If you think that's amazing, I encourage you to read more about the extreme sensory capabilities of nonhuman animals; many animals possess what we would consider super-human abilities.

A similar principle to the absolute threshold discussed above underlies our ability to detect the difference between two stimuli of different intensities. The **differential threshold** (or difference threshold) or **just noticeable difference (JND)**, for each sense has been studied using similar methods to signal detection. To illustrate, find a friend and a few objects of known weight (you'll need objects that weigh 1, 2, 10 and 11 lbs.—or in metric terms: 1, 2, 5 and 5.5 kg). Have your friend hold the lightest object (1 lb. or 1 kg). Then, replace this object with the next heaviest and ask him or her to tell you which one weighs more. Reliably, your friend will say the second object every single time. It's extremely easy to tell the difference when something weighs double what another weighs! However, it is not so easy when the difference is a smaller percentage of the overall weight. It will be much harder for your friend to reliably tell the difference between 10 and 11 lbs. (or 5 versus 5.5 kg) than it is for 1 and 2 lbs. This is phenomenon is called **Weber's Law**, and it is the idea that bigger stimuli require larger differences to be noticed. As with the absolute threshold, your ability to notice differences varies throughout the day and based on what other stimuli you have recently experienced so the difference threshold is defined as the smallest difference detectable 50% of the time.

Crossing into the world of perception, it is clear that our experience influences how our brain processes things. You have tasted food that you like and food that you don't like. There are some bands you enjoy and others you can't stand. However, during the time you first eat something or hear a band, you process those stimuli using **bottom-up processing**. This is when we build up to perception from the individual pieces. Sometimes, though, stimuli we've experienced in our past will influence how we process new ones. This is called **top-down processing**. The best way to illustrate these two concepts is with our ability to read. Read the following quote out loud:

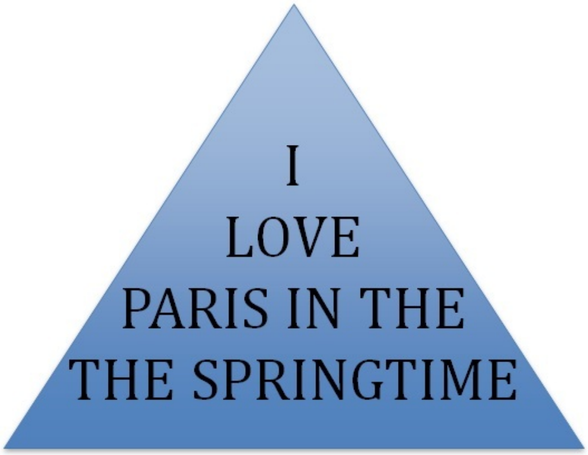

Figure 1. An example of stimuli processing.

Notice anything odd while you were reading the text in the triangle? Did you notice the second "the"? If not, it's likely because you were reading this from a top-down approach. Having a second "the" doesn't make sense. We know this. Our brain knows this and doesn't *expect* there to be a second one, so we have a tendency to skip right over it. In other words, your past experience has changed the way you perceive the writing in the triangle! A beginning reader —one who is using a bottom-up approach by carefully attending to each piece—would be less likely to make this error.

Finally, it should be noted that when we experience a sensory stimulus that doesn't change, we stop paying attention to it. This is why we don't feel the weight of our clothing, hear the hum of a projector in a lecture hall, or see all the tiny scratches on the lenses of our glasses. When a stimulus is constant and unchanging, we experience **sensory adaptation**. This occurs because if a stimulus does not change, our receptors quit responding to it. A great example of this occurs when we leave the radio on in our car after we park it at home for the night. When we listen to the radio on the way home from work the volume seems reasonable. However, the next morning when we start the car, we might be startled by how loud the radio is. We don't remember it being that loud last night. What happened? We adapted to the constant stimulus (the radio volume) over the course of the previous day and increased the volume at various times.

Now that we have introduced some basic sensory principles, let us take on each one of our fascinating senses individually.

Vision

How vision works

Vision is a tricky matter. When we see a pizza, a feather, or a hammer, we are actually seeing light bounce off that object and into our eye. Light enters the eye through the pupil, a tiny opening behind the cornea. The pupil regulates the amount of light entering the eye by contracting (getting smaller) in bright light and dilating (getting larger) in dimmer light. Once past the pupil, light passes through the lens, which focuses an image on a thin layer of cells in the back of the eye, called the retina.

Because we have two eyes in different locations, the image focused on each retina is from a slightly different angle (binocular disparity), providing us with our perception of 3D space (binocular vision). You can appreciate this by holding a pen in your hand, extending your arm in front of your face, and looking at the pen while closing each eye in turn. Pay attention to

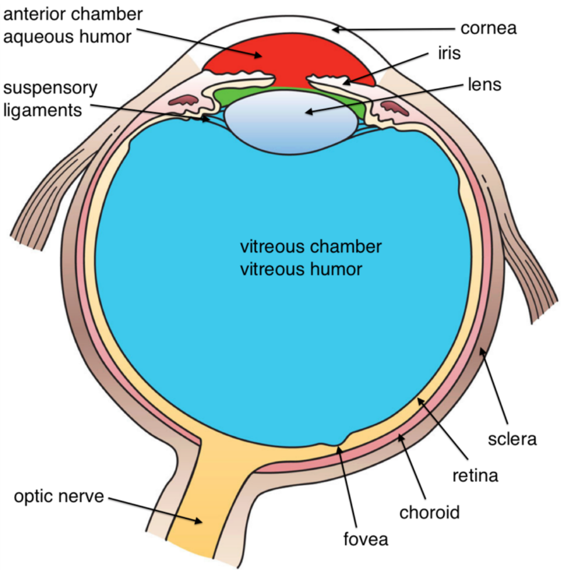

Figure 2. Diagram of the human eye. Notice the Retina, labeled here: this is the location of the Cones and Rods in the eye. [Image: Holly Fischer, https://goo.gl/ozuG0Q, CC BY 3.0, https://goo.gl/TSIsIq]

the apparent position of the pen relative to objects in the background. Depending on which eye is open, the pen appears to jump back and forth! This is how video game manufacturers create the perception of 3D without special glasses; two slightly different images are presented on top of one another.

It is in the retina that light is transduced, or converted into electrical signals, by specialized cells called photoreceptors. The retina contains two main kinds of photoreceptors: rods and cones. Rods are primarily responsible for our ability to see in dim light conditions, such as during the night. Cones, on the other hand, provide us with the ability to see color and fine detail when the light is brighter. Rods and cones differ in their distribution across the retina, with the highest concentration of cones found in the fovea (the central region of focus), and rods dominating the periphery (see Figure 2). The difference in distribution can explain why looking directly at a dim star in the sky makes it seem to disappear; there aren't enough rods to process the dim light!

Next, the electrical signal is sent through a layer of cells in the retina, eventually traveling down the optic nerve. After passing through the thalamus, this signal makes it to the primary visual cortex, where information about light orientation and movement begin to come together (Hubel & Wiesel, 1962). Information is then sent to a variety of different areas of the cortex for more complex processing. Some of these cortical regions are fairly specialized—for example, for processing faces (fusiform face area) and body parts (extrastriate body area). Damage to these areas of the cortex can potentially result in a specific kind of agnosia, whereby a person loses the ability to perceive visual stimuli. A great example of this is illustrated in the writing of famous neurologist Dr. Oliver Sacks; he experienced *prosopagnosia*, the inability to recognize faces. These specialized regions for visual recognition comprise the ventral pathway (also called the "what" pathway). Other areas involved in processing location and movement make up the dorsal pathway (also called the "where" pathway). Together, these pathways process a large amount of information about visual stimuli (Goodale & Milner, 1992). Phenomena we often refer to as optical illusions provide misleading information to these "higher" areas of visual processing (see Additional Resources for websites containing amazing optical illusions).

Dark and light adaptation

Humans have the ability to adapt to changes in light conditions. As mentioned before, rods are primarily involved in our ability to see in dim light. They are the photoreceptors responsible for allowing us to see in a dark room. You might notice that this night vision ability takes around 10 minutes to turn on, a process called dark adaptation. This is because our rods become bleached in normal light conditions and require time to recover. We experience the opposite effect when we leave a dark movie theatre and head out into the afternoon sun. During light adaptation, a large number of rods and cones are bleached at once, causing us to be blinded for a few seconds. Light adaptation happens almost instantly compared with dark adaptation. Interestingly, some people think pirates wore a patch over one eye in order to keep it adapted to the dark while the other was adapted to the light. If you want to turn on a light without losing your night vision, don't worry about wearing an eye patch, just use a red light; this wavelength doesn't bleach your rods.

Color vision

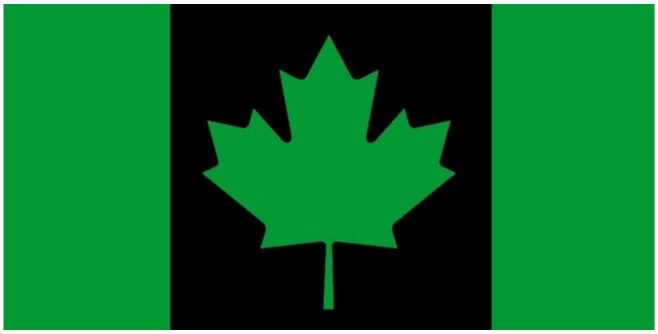

Figure 3. Stare at the center of the Canadian flag for fifteen seconds. Then, shift your eyes away to a white wall or blank piece of paper. You should see an "after image" in a different color scheme.

Our cones allow us to see details in normal light conditions, as well as color. We have cones that respond *preferentially,* not exclusively, for red, green and blue (Svaetichin, 1955). This trichromatic theory is not new; it dates back to the early 19th century (Young, 1802; Von Helmholtz, 1867). This theory, however, does not explain the odd effect that occurs when we look at a white wall after staring at a picture for around 30 seconds. Try this: stare at the image of the flag in Figure 3 for 30 seconds and then immediately look at a sheet of white paper or a wall. According to the trichromatic theory of color vision, you should see white when you do that. Is that what you experienced? As you can see, the trichromatic theory doesn't explain the *afterimage* you just witnessed. This is where the opponent-process theory comes in (Hering, 1920). This theory states that our cones send information to *retinal ganglion cells* that respond to *pairs* of colors (red-green, blue-yellow, black-white). These specialized cells take information from the cones and compute the difference between the two colors—a process that explains why we cannot see reddish-green or bluish-yellow, as well as why we see afterimages. Color deficient vision can result from issues with the cones or retinal ganglion cells involved in color vision.

Hearing (Audition)

Some of the most well-known celebrities and top earners in the world are musicians. Our worship of musicians may seem silly when you consider that all they are doing is vibrating the air a certain way to create sound waves, the physical stimulus for audition.

People are capable of getting a large amount of information from the basic qualities of sound waves. The *amplitude* (or intensity) of a sound wave codes for the loudness of a stimulus; higher amplitude sound waves result in louder sounds. The *pitch* of a stimulus is coded in the *frequency* of a sound wave; higher frequency sounds are higher pitched. We can also gauge the quality, or *timbre*, of a sound by the complexity of the sound wave. This allows us to tell the difference between bright and dull sounds as well as natural and synthesized instruments (Välimäki & Takala, 1996).

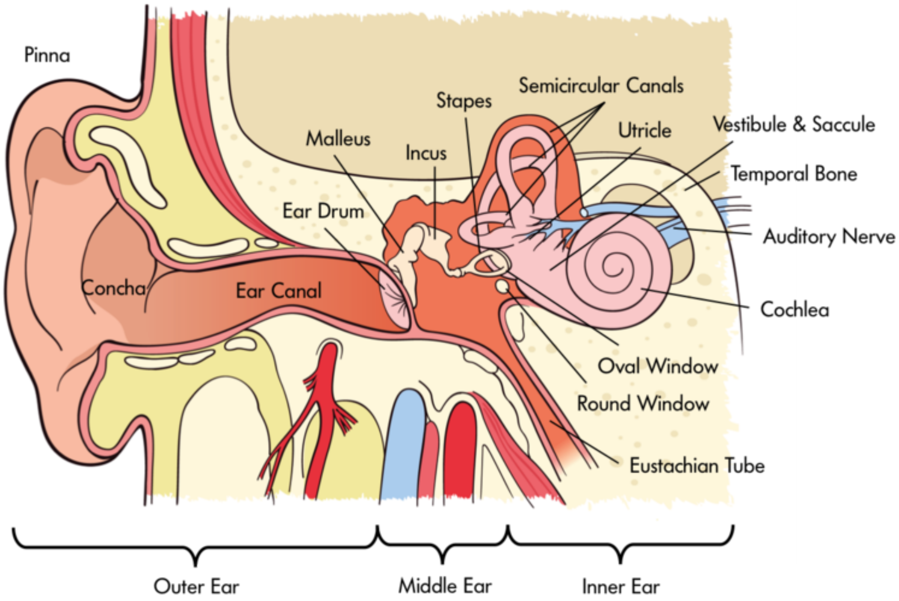

Figure 4. Diagram of the human ear. Notice the Cochlea labeled here: it is the location of the auditory Hair Cells that are tonotopically organized.

In order for us to sense sound waves from our environment they must reach our inner ear. Lucky for us, we have evolved tools that allow those waves to be funneled and amplified during this journey. Initially, sound waves are funneled by your pinna (the external part of your ear that you can actually see) into your auditory canal (the hole you stick Q-tips into despite the box advising against it). During their journey, sound waves eventually reach a thin, stretched membrane called the tympanic membrane (eardrum), which vibrates against the three smallest bones in the body—the malleus (hammer), the incus (anvil), and the stapes (stirrup)—collectively called the ossicles. Both the tympanic membrane and the ossicles amplify the sound waves before they enter the fluid-filled cochlea, a snail-shell-like bone structure containing auditory hair cells arranged on the basilar membrane (see Figure 4) according to the frequency they respond to (called tonotopic organization). Depending on age, humans can normally detect sounds between 20 Hz and 20 kHz. It is inside the cochlea that sound waves are converted into an electrical message.

Because we have an ear on each side of our head, we are capable of localizing sound in 3D space pretty well (in the same way that having two eyes produces 3D vision). Have you ever dropped something on the floor without seeing where it went? Did you notice that you were somewhat capable of locating this object based on the sound it made when it hit the ground? We can reliably locate something based on which ear receives the sound first. What about the height of a sound? If both ears receive a sound at the same time, how are we capable of localizing sound vertically? Research in cats (Populin & Yin, 1998) and humans (Middlebrooks & Green, 1991) has pointed to differences in the quality of sound waves depending on vertical positioning.

After being processed by auditory hair cells, electrical signals are sent through the *cochlear nerve* (a division of the vestibulocochlear nerve) to the thalamus, and then the primary auditory cortex of the temporal lobe. Interestingly, the tonotopic organization of the cochlea is maintained in this area of the cortex (Merzenich, Knight, & Roth, 1975; Romani, Williamson, & Kaufman, 1982). However, the role of the primary auditory cortex in processing the wide range of features of sound is still being explored (Walker, Bizley, & Schnupp, 2011).

Balance and the vestibular system

The inner ear isn't only involved in hearing; it's also associated with our ability to balance and detect where we are in space. The vestibular system is comprised of three semicircular canals —fluid-filled bone structures containing cells that respond to changes in the head's orientation in space. Information from the vestibular system is sent through the vestibular nerve (the other division of the vestibulocochlear nerve) to muscles involved in the movement of our eyes, neck, and other parts of our body. This information allows us to maintain our gaze on an object while we are in motion. Disturbances in the vestibular system can result in issues with balance, including vertigo.

Touch

Who doesn't love the softness of an old t-shirt or the smoothness of a clean shave? Who actually enjoys having sand in their swimsuit? Our skin, the body's largest organ, provides us with all sorts of information, such as whether something is smooth or bumpy, hot or cold, or even if it's painful. Somatosensation—which includes our ability to sense touch, temperature and pain—transduces physical stimuli, such as fuzzy velvet or scalding water, into electrical potentials that can be processed by the brain.

Tactile sensation

Tactile stimuli—those that are associated with texture—are transduced by special receptors in the skin called mechanoreceptors. Just like photoreceptors in the eye and auditory hair cells in the ear, these allow for the conversion of one kind of energy into a form the brain can understand.

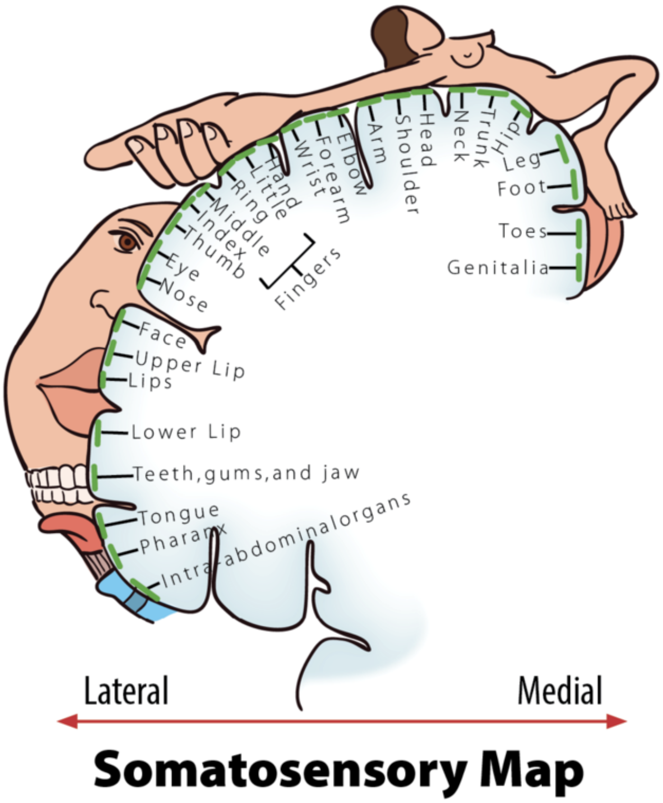

Figure 5. A drawing of the somatosensory cortex in the brain and the areas in the human body that correspond to it - they are drawn in proportion to the most sensitive or the most innervated parts of the body.

After tactile stimuli are converted by mechanoreceptors, information is sent through the thalamus to the primary somatosensory cortex for further processing. This region of the cortex is organized in a somatotopic map where different regions are sized based on the sensitivity of specific parts on the opposite side of the body (Penfield & Rasmussen, 1950). Put simply, various areas of the skin, such as lips and fingertips, are more sensitive than others, such as shoulders or ankles. This sensitivity can be represented with the distorted proportions of the human body shown in Figure 5.

Pain

Most people, if asked, would love to get rid of pain (nociception), because the sensation is very unpleasant and doesn't appear to have obvious value. But the perception of pain is our body's way of sending us a signal that something is wrong and needs our attention. Without pain, how would we know when we are accidentally touching a hot stove, or that we should rest a strained arm after a hard workout?

Phantom limbs

Records of people experiencing phantom limbs after amputations have been around for centuries (Mitchell, 1871). As the name suggests, people with a phantom limb have the sensations such as itching seemingly coming from their missing limb. A phantom limb can also involve phantom limb pain, sometimes described as the muscles of the missing limb uncomfortably clenching. While the mechanisms underlying these phenomena are not fully understood, there is evidence to support that the damaged nerves from the amputation site are still sending information to the brain (Weinstein, 1998) and that the brain is reacting to this information (Ramachandran & Rogers-Ramachandran, 2000). There is an interesting treatment for the alleviation of phantom limb pain that works by tricking the brain, using a special mirror box to create a visual representation of the missing limb. The technique allows the patient to manipulate this representation into a more comfortable position (Ramachandran & Rogers-Ramachandran, 1996).

Smell and Taste: The Chemical Senses

The two most underappreciated senses can be lumped into the broad category of chemical senses. Both olfaction (smell) and gustation (taste) require the transduction of chemical stimuli into electrical potentials. I say these senses are underappreciated because most people would give up either one of these if they were forced to give up a sense. While this may not shock a lot of readers, take into consideration how much money people spend on the perfume industry annually ($29 billion US Dollars). Many of us pay a lot more for a favorite brand of food because we prefer the taste. Clearly, we humans care about our chemical senses.

Olfaction (smell)

Unlike any of the other senses discussed so far, the receptors involved in our perception of both smell and taste bind directly with the stimuli they transduce. Odorants in our environment, very often mixtures of them, bind with olfactory receptors found in the olfactory epithelium. The binding of odorants to receptors is thought to be similar to how a lock and key operates, with different odorants binding to different specialized receptors based on their shape. However, the shape theory of olfaction isn't universally accepted and alternative theories exist, including one that argues that the vibrations of odorant molecules correspond to their subjective smells (Turin, 1996). Regardless of how odorants bind with receptors, the result is a pattern of neural activity. It is thought that our memories of these patterns of activity underlie our subjective experience of smell (Shepherd, 2005). Interestingly, because olfactory receptors send projections to the brain through the *cribriform plate* of the skull, head trauma has the potential to cause anosmia, due to the severing of these connections. If you are in a line of work where you constantly experience head trauma (e.g. professional boxer) and you develop anosmia, don't worry—your sense of smell will probably come back (Sumner, 1964).

Gustation (taste)

Taste works in a similar fashion to smell, only with receptors found in the taste buds of the tongue, called taste receptor cells. To clarify a common misconception, taste buds are not the bumps on your tongue (papillae), but are located in small divots around these bumps. These receptors also respond to chemicals from the outside environment, except these chemicals, called tastants, are contained in the foods we eat. The binding of these chemicals with taste receptor cells results in our perception of the five basic tastes: sweet, sour, bitter, salty and umami (savory)—although some scientists argue that there are more (Stewart et al., 2010). Researchers used to think these tastes formed the basis for a map-like organization of the tongue; there was even a clever rationale for the concept, about how the back of the tongue sensed

Ghost Pepper, also known as Bhut Jolokia is one of the hottest peppers in the world, it's 10 times hotter than a habanero, and 400 times hotter than tabasco sauce. What do you think would happen to your taste receptor cells if you took a bite out of this little guy? [Image: Richard Elzey, https://goo.gl/suJHNg, CC BY 2.0, https://goo.gl/9uSnqN] bitter so we would know to spit out poisons, and the front of the tongue sensed sweet so we could identify high-energy foods. However, we now know that all areas of the tongue with taste receptor cells are capable of responding to every taste (Chandrashekar, Hoon, Ryba, & Zuker, 2006).

During the process of eating we are not limited to our sense of taste alone. While we are chewing, food odorants are forced back up to areas that contain olfactory receptors. This combination of taste and smell gives us the perception of **flavor**. If you have doubts about the interaction between these two senses, I encourage you to think back to consider how the flavors of your favorite foods are impacted when you have a cold; everything is pretty bland and boring, right?

Putting it all Together: Multimodal Perception

Though we have spent the majority of this module covering the senses individually, our real-world experience is most often multimodal, involving combinations of our senses into one perceptual experience. This should be clear after reading the description of walking through the forest at the beginning of the module; it was the combination of senses that allowed for that experience. It shouldn't shock you to find out that at some point information from each of our senses becomes integrated. Information from one sense has the potential to influence how we perceive information from another, a process called **multimodal perception**.

Interestingly, we actually respond more strongly to multimodal stimuli compared to the sum of each single modality together, an effect called the **superadditive effect of multisensory integration**. This can explain how you're still able to understand what friends are saying to you at a loud concert, as long as you are able to get visual cues from watching them speak. If you were having a quiet conversation at a café, you likely wouldn't need these additional cues. In fact, the **principle of inverse effectiveness** states that you are *less* likely to benefit from additional cues from other modalities if the initial unimodal stimulus is strong enough (Stein & Meredith, 1993).

Because we are able to process multimodal sensory stimuli, and the results of those processes are qualitatively different from those of unimodal stimuli, it's a fair assumption that the brain is doing something qualitatively different when they're being processed. There has been a growing body of evidence since the mid-90's on the neural correlates of multimodal perception. For example, neurons that respond to both visual and auditory stimuli have been identified in the *superior temporal sulcus* (Calvert, Hansen, Iversen, & Brammer, 2001). Additionally, multimodal "what" and "where" pathways have been proposed for auditory and tactile stimuli (Renier et al., 2009). We aren't limited to reading about these regions of the brain and what they do; we can experience them with a few interesting examples (see Additional Resources for the "McGurk Effect," the "Double Flash Illusion," and the "Rubber Hand Illusion").

Conclusion

Our impressive sensory abilities allow us to experience the most enjoyable and most miserable experiences, as well as everything in between. Our eyes, ears, nose, tongue and skin provide an interface for the brain to interact with the world around us. While there is simplicity in covering each sensory modality independently, we are organisms that have evolved the ability to process multiple modalities as a unified experience.

Outside Resources

Audio: Auditory Demonstrations from Richard Warren's lab at the University of Wisconsin, Milwaukee
http://www4.uwm.edu/APL/demonstrations.html

Audio: Auditory Demonstrations. CD published by the Acoustical Society of America (ASA). You can listen to the demonstrations here
http://www.feilding.net/sfuad/musi3012-01/demos/audio/

Book: Ackerman, D. (1990). A natural history of the senses. Vintage.
http://www.dianeackerman.com/a-natural-history-of-the-senses-by-diane-ackerman

Book: Sacks, O. (1998). The man who mistook his wife for a hat: And other clinical tales. Simon and Schuster.
http://www.oliversacks.com/books-by-oliver-sacks/man-mistook-wife-hat/

Video: Acquired knowledge and its impact on our three-dimensional interpretation of the world - 3D Street Art
https://youtu.be/GwNeukAmxJw

Video: Acquired knowledge and its impact on our three-dimensional interpretation of the world - Anamorphic Illusions
https://youtu.be/tBNHPk-Lnkk

Video: Cybersenses
https://www.youtube.com/watch?v=_8rPD6xLB4A

Video: Seeing Sound, Tasting Color
https://www.youtube.com/watch?v=FTr1VnXKr4A

Video: The Phantom Limb Phenomenon
https://www.youtube.com/watch?v=1mHIv5ToMTM

Web: A regularly updated website covering some of the amazing sensory capabilities of non-human animals.
http://phenomena.nationalgeographic.com/category/animal-senses/

Web: A special ringtone that is only audible to younger people.
https://www.youtube.com/watch?v=IrewnzQYrPI

Web: Amazing library with visual phenomena and optical illusions, explained
http://michaelbach.de/ot/index.html

Web: An article on the discoveries in echolocation: the use of sound in locating people and things
http://www.psychologicalscience.org/index.php/publications/observer/2015/december-15/using-sound-to-get-around.html

Web: An optical illusion demonstration the opponent-process theory of color vision.
https://www.youtube.com/watch?v=qA2brNUo7WA

Web: Anatomy of the eye
http://www.eyecareamerica.org/eyecare/anatomy/

Web: Animation showing tonotopic organization of the basilar membrane.
https://www.youtube.com/watch?v=dyenMluFaUw

Web: Best Illusion of the Year Contest website
http://illusionoftheyear.com/

Web: Demonstration of contrast gain adaptation
http://www.michaelbach.de/ot/lum_contrast-adapt/

Web: Demonstration of illusory contours and lateral inhibition. Mach bands
http://michaelbach.de/ot/lum-MachBands/index.html

Web: Demonstration of illusory contrast and lateral inhibition. The Hermann grid
http://michaelbach.de/ot/lum_herGrid/

Web: Demonstrations and illustrations of cochlear mechanics can be found here
http://lab.rockefeller.edu/hudspeth/graphicalSimulations

Web: Double Flash Illusion
https://vimeo.com/39138252

Web: Further information regarding what and where/how pathways

http://www.scholarpedia.org/article/What_and_where_pathways

Web: Great website with a large collection of optical illusions
http://www.michaelbach.de/ot/

Web: McGurk Effect Video
https://www.youtube.com/watch?v=G-lN8vWm3m0

Web: More demonstrations and illustrations of cochlear mechanics
http://www.neurophys.wisc.edu/animations/

Web: Scientific American Frontiers: Cybersenses
http://www.pbs.org/saf/1509/

Web: The Genetics of Taste
http://www.smithsonianmag.com/arts-culture/the-genetics-of-taste-88797110/?no-ist

Web: The Monell Chemical Sense Center website
http://www.monell.org/

Web: The Rubber Hand Illusion
https://www.youtube.com/watch?v=sxwn1w7MJvk

Web: The Tongue Map: Tasteless Myth Debunked
http://www.livescience.com/7113-tongue-map-tasteless-myth-debunked.html

Discussion Questions

1. There are a number of myths that exist about the sensory capabilities of infants. How would you design a study to determine what the true sensory capabilities of infants are?
2. A well-documented phenomenon experienced by millennials is the phantom vibration of a cell phone when no actual text message has been received. How can we use signal detection theory to explain this?
3. What physical features would an organism need in order to be really good at localizing sound in 3D space? Are there any organisms that currently excel in localizing sound? What features allow them to do this?

4. What issues would exist with visual recognition of an object if a research participant had his/her corpus callosum severed? What would you need to do in order to observe these deficits?

Vocabulary

Absolute threshold
The smallest amount of stimulation needed for detection by a sense.

Agnosia
Loss of the ability to perceive stimuli.

Anosmia
Loss of the ability to smell.

Audition
Ability to process auditory stimuli. Also called hearing.

Auditory canal
Tube running from the outer ear to the middle ear.

Auditory hair cells
Receptors in the cochlea that transduce sound into electrical potentials.

Binocular disparity
Difference is images processed by the left and right eyes.

Binocular vision
Our ability to perceive 3D and depth because of the difference between the images on each of our retinas.

Bottom-up processing
Building up to perceptual experience from individual pieces.

Chemical senses
Our ability to process the environmental stimuli of smell and taste.

Cochlea
Spiral bone structure in the inner ear containing auditory hair cells.

Cones
Photoreceptors of the retina sensitive to color. Located primarily in the fovea.

Dark adaptation
Adjustment of eye to low levels of light.

Differential threshold (or difference threshold)
The smallest difference needed in order to differentiate two stimuli. (See Just Noticeable Difference (JND))

Dorsal pathway
Pathway of visual processing. The “where” pathway.

Flavor
The combination of smell and taste.

Gustation
Ability to process gustatory stimuli. Also called taste.

Just noticeable difference (JND)
The smallest difference needed in order to differentiate two stimuli. (see Differential Threshold)

Light adaptation
Adjustment of eye to high levels of light.

Mechanoreceptors
Mechanical sensory receptors in the skin that response to tactile stimulation.

Multimodal perception
The effects that concurrent stimulation in more than one sensory modality has on the perception of events and objects in the world.

Nociception
Our ability to sense pain.

Odorants
Chemicals transduced by olfactory receptors.

Olfaction
Ability to process olfactory stimuli. Also called smell.

Olfactory epithelium
Organ containing olfactory receptors.

Opponent-process theory
Theory proposing color vision as influenced by cells responsive to pairs of colors.

Ossicles
A collection of three small bones in the middle ear that vibrate against the tympanic membrane.

Perception
The psychological process of interpreting sensory information.

Phantom limb
The perception that a missing limb still exists.

Phantom limb pain
Pain in a limb that no longer exists.

Pinna
Outermost portion of the ear.

Primary auditory cortex
Area of the cortex involved in processing auditory stimuli.

Primary somatosensory cortex
Area of the cortex involved in processing somatosensory stimuli.

Primary visual cortex
Area of the cortex involved in processing visual stimuli.

Principle of inverse effectiveness
The finding that, in general, for a multimodal stimulus, if the response to each unimodal component (on its own) is weak, then the opportunity for multisensory enhancement is very large. However, if one component—by itself—is sufficient to evoke a strong response, then the effect on the response gained by simultaneously processing the other components of the stimulus will be relatively small.

Retina

Cell layer in the back of the eye containing photoreceptors.

Rods
Photoreceptors of the retina sensitive to low levels of light. Located around the fovea.

Sensation
The physical processing of environmental stimuli by the sense organs.

Sensory adaptation
Decrease in sensitivity of a receptor to a stimulus after constant stimulation.

Shape theory of olfaction
Theory proposing that odorants of different size and shape correspond to different smells.

Signal detection
Method for studying the ability to correctly identify sensory stimuli.

Somatosensation
Ability to sense touch, pain and temperature.

Somatotopic map
Organization of the primary somatosensory cortex maintaining a representation of the arrangement of the body.

Sound waves
Changes in air pressure. The physical stimulus for audition.

Superadditive effect of multisensory integration
The finding that responses to multimodal stimuli are typically greater than the sum of the independent responses to each unimodal component if it were presented on its own.

Tastants
Chemicals transduced by taste receptor cells.

Taste receptor cells
Receptors that transduce gustatory information.

Top-down processing
Experience influencing the perception of stimuli.

Transduction
The conversion of one form of energy into another.

Trichromatic theory
Theory proposing color vision as influenced by three different cones responding preferentially to red, green and blue.

Tympanic membrane
Thin, stretched membrane in the middle ear that vibrates in response to sound. Also called the eardrum.

Ventral pathway
Pathway of visual processing. The “what” pathway.

Vestibular system
Parts of the inner ear involved in balance.

Weber’s law
States that just noticeable difference is proportional to the magnitude of the initial stimulus.

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4
Vision

Simona Buetti & Alejandro Lleras

Vision is the sensory modality that transforms light into a psychological experience of the world around you, with minimal bodily effort. This module provides an overview of the most significant steps in this transformation and strategies that your brain uses to achieve this visual understanding of the environment.

Learning Objectives

- Describe how the eye transforms light information into neural energy.
- Understand what sorts of information the brain is interested in extracting from the environment and why it is useful.
- Describe how the visual system has adapted to deal with different lighting conditions.
- Understand the value of having two eyes.
- Understand why we have color vision.
- Understand the interdependence between vision and other brain functions.

What Is Vision?

Think about the spectacle of a starry night. You look up at the sky, and thousands of photons from distant stars come crashing into your retina, a light-sensitive structure at the back of your eyeball. These photons are millions of years old and have survived a trip across the universe, only to run into one of your photoreceptors. Tough luck: in one thousandth of a second, this little bit of light energy becomes the fuel to a photochemical reaction known as photoactivation. The light energy becomes neural energy and triggers a cascade of neural activity that, a few hundredths of a second later, will result in your becoming aware of that distant star. You and the universe united by photons. That is the amazing power of vision. Light brings the world to you. Without moving, you know what's out there. You can recognize friends coming to meet you before you are able to hear them coming, ripe fruits from green ones on trees without having to taste them and before reaching out to grab them. You can also tell how quickly a ball is moving in your direction (Will it hit you? Can you hit it?).

How does all of that happen? First, light enters the eyeball through a tiny hole known as the pupil and, thanks to the refractive properties of your cornea and lens, this light signal gets projected sharply into the retina (see Outside Resources for links to a more detailed description of the eye structure). There, light is transduced into neural energy by about 200 million photoreceptor cells.

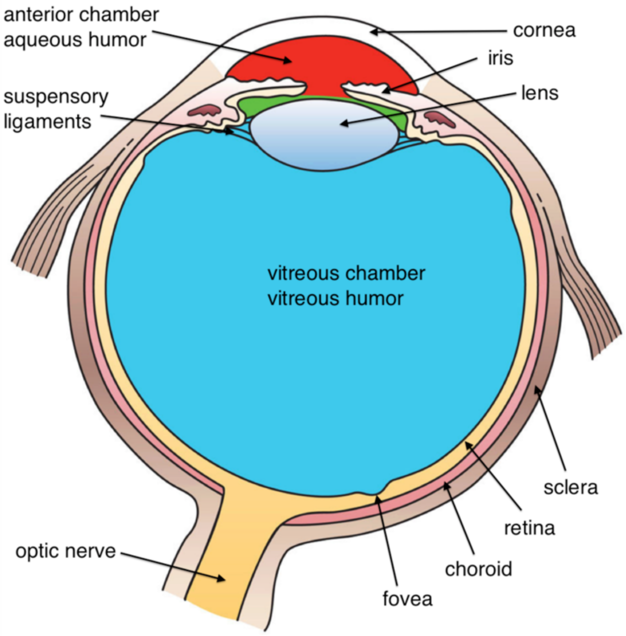

Diagram of the human eye [Image: Holly Fischer, https://goo.gl/cMOQdh, CC BY 3.0, https://goo.gl/EHHVdU]

This is where the information carried by the light about distant objects and colors starts being encoded by our brain. There are two different types of photoreceptors: rods and cones. The human eye contains more rods than cones. Rods give us sensitivity under dim lighting conditions and allow us to see at night. Cones allow us to see fine details in bright light and give us the sensation of color. Cones are tightly packed around the fovea (the central region of the retina behind your pupil) and more sparsely elsewhere. Rods populate the periphery (the region surrounding the fovea) and are almost absent from the fovea.

But vision is far more complex than just catching photons. The information encoded by the photoreceptors undergoes a rapid and continuous set of ever more complex analysis so that, eventually, you can make sense of what's out there. At the fovea, visual information is encoded separately from tiny portions of the world (each about half the width of a human hair viewed at arm's length) so that eventually the brain can reconstruct in great detail fine visual differences from locations at which you are directly looking. This fine level of encoding requires lots of light and it is slow going (neurally speaking). In contrast, in the periphery, there is a different encoding strategy: detail is sacrificed in exchange for sensitivity. Information is summed across larger sections of the world. This aggregation occurs quickly and allows you to detect dim signals under very low levels of light, as well as detect sudden movements in your peripheral vision.

The Importance of Contrast

What happens next? Well, you might think that the eye would do something like record the amount of light at each location in the world and then send this information to the visual-processing areas of the brain (an astounding 30% of the cortex is influenced by visual signals!). But, in fact, that is not what eyes do. As soon as photoreceptors capture light, the nervous system gets busy analyzing *differences* in light, and it is these differences that get transmitted to the brain. The brain, it turns out, cares little about the overall amount of light coming from a specific part of the world, or in the scene overall. Rather, it wants to know: does the light coming from this one point differ from the light coming from the point next to it? Place your hand on the table in front of you. The contour of your hand is actually determined by the difference in light—the **contrast**—between the light coming from the skin in your hand and the light coming from the table underneath. To find the contour of your hand, we simply need to find the regions in the image where the difference in light between two adjacent points is maximal. Two points on your skin will reflect similar levels of light back to you, as will two points on the table. On the other hand, two points that fall on either side of the boundary contour between your hand and the table will reflect very different light.

The fact that the brain is interested in coding contrast in the world reveals something deeply important about the forces that drove the evolution of our brain: encoding the absolute amount of light in the world tells us little about what is out there. But if your brain can detect the sudden appearance of a *difference* in light somewhere in front of you, then it must be that something new is there. That contrast signal is *information*. That information may represent something that you like (food, a friend) or something dangerous approaching (a tiger, a cliff). The rest of your visual system will work hard to determine what that thing is, but as quickly as 10ms after light enters your eyes, ganglion cells in your retinae have already encoded all the differences in light from the world in front of you.

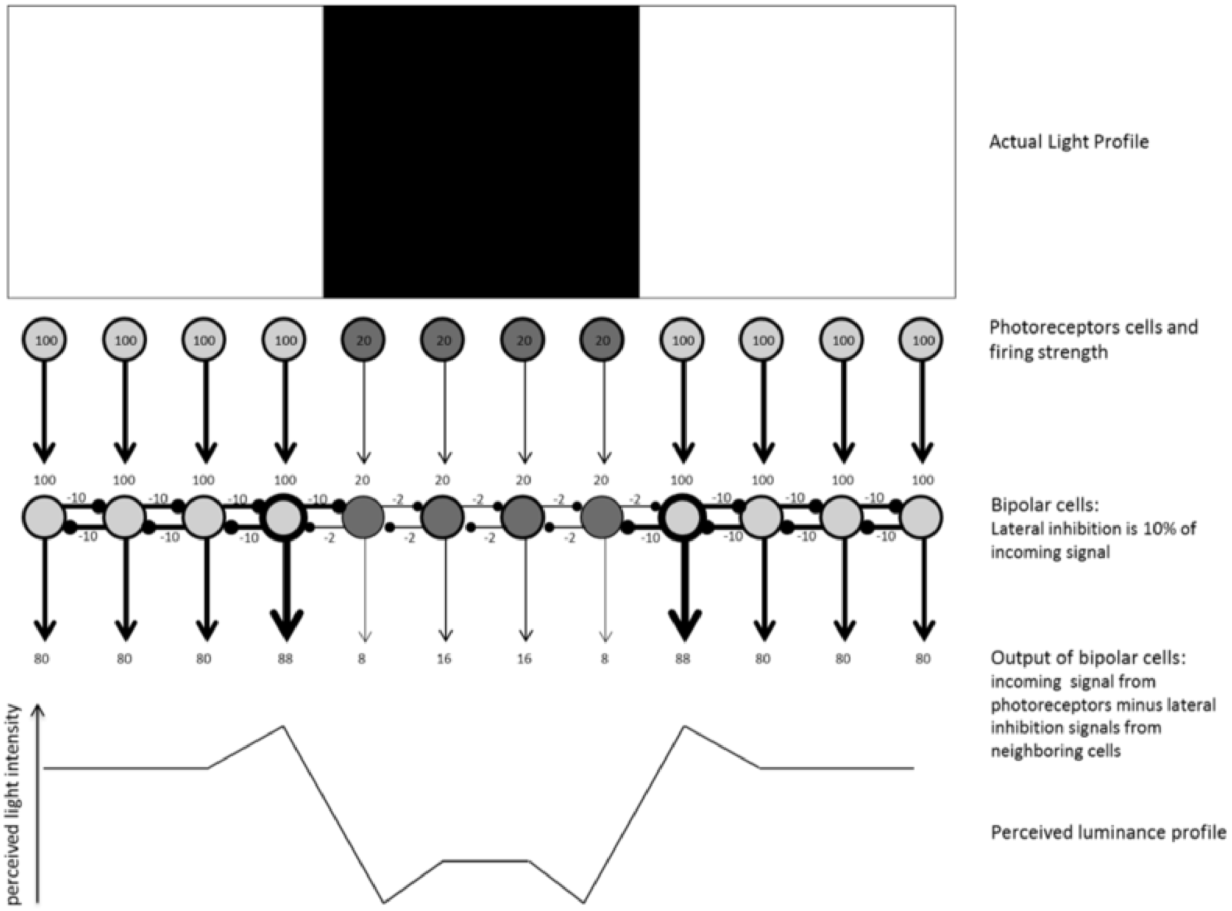

Figure 1. Illustration of Lateral Inhibition at work. The top of the figure shows a black stripe on a white background. The first row of circles illustrates photoreceptors responding in a graded fashion: the more light hits them, the more they fire. The numbers inside the circles represent how much these cells are firing, and the thickness of lines is also meant to illustrate the strength of neural firing. These photoreceptors activate the next layer of neurons in the retina: bipolar cells. These cells produce lateral inhibition signals, depicted by the horizontal lines that end with a small circle. The inhibition signals are proportional (here, 10% for ease) to the excitatory input they receive. Cells receiving 100 units will inhibit their neighbors by 10 units. Cells receiving 20 units will inhibit their neighbors by 2 units. The output of a bipolar cell will be determined by the input it receives minus all the lateral inhibition signals from its neighbors. As a result of the inhibition, notice how on the bright side of the edges, the firing rates are the highest (88) compared to nearby neurons just coding bright light (80). These higher values near the edge occur because these cells receive a comparatively small amount of inhibition from their “dark-side” neighbor (-2). Similarly, on the dark side of the edge, the firing rates are the lowest (8) of all the dark region (16) because these cells receive a comparatively large amount of inhibition from their “bright-side” neighbor (-10). Overall, the image is coded as a black stripe surrounded by brighter light, but now, thanks to lateral inhibition, all the edges in the image have been emphasized (enhanced), as illustrated by the perceived luminance profile at the bottom of the image.

Contrast is so important that your neurons go out of their way not only to encode differences in light but to exaggerate those differences for you, lest you miss them. Neurons achieve this via a process known as lateral inhibition. When a neuron is firing in response to light, it produces two signals: an output signal to pass on to the next level in vision, and a lateral signal to inhibit all neurons that are next to it. This makes sense on the assumption that nearby neurons are likely responding to the same light coming from nearby locations, so this information is somewhat redundant. The magnitude of the lateral inhibitory signal a neuron produces is proportional to the excitatory input that neuron receives: the more a neuron fires, the stronger the inhibition it produces. Figure 1 illustrates how lateral inhibition amplifies contrast signals at the edges of surfaces.

Sensitivity to Different Light Conditions

Rods and cones work in tandem to help you adjust when moving between extremes of dark and light. [Image: Pexels, CC0 Public Domain, https://goo.gl/m25gce]

Let's think for a moment about the range of conditions in which your visual system must operate day in and day out. When you take a walk outdoors on a sunny day, as many as billions of photons enter your eyeballs every second. In contrast, when you wake up in the middle of the night in a dark room, there might be as little as a few hundred photons per second entering your eyes. To deal with these extremes, the visual system relies on the different properties of the two types of photoreceptors. Rods are mostly responsible for processing light when photons are scarce (just a single photon can make a rod fire!), but it takes time to replenish the visual pigment that rods require for photoactivation. So, under bright conditions, rods are quickly bleached (Stuart & Brige, 1996) and cannot keep up with the constant barrage of photons hitting them. That's when the cones become useful. Cones require more photons to fire and, more critically, their photopigments replenish much faster than rods' photopigments, allowing them to keep up when photons are abundant.

What happens when you abruptly change lighting conditions? Under bright light, your rods are bleached. When you move into a dark environment, it will take time (up to 30 minutes) before they chemically recover (Hurley, 2002). Once they do, you will begin to see things around you that initially you could not. This phenomenon is called **dark adaptation**. When you go from dark to bright light (as you exit a tunnel on a highway, for instance), your rods will be bleached in a blaze and you will be blinded by the sudden light for about 1 second. However, your cones are ready to fire! Their firing will take over and you will quickly begin to see at this higher level of light.

A similar, but more subtle, adjustment occurs when the change in lighting is not so drastic. Think about your experience of reading a book at night in your bed compared to reading outdoors: the room may feel to you fairly well illuminated (enough so you can read) but the light bulbs in your room are not producing the billions of photons that you encounter outside. In both cases, you feel that your experience is that of a well-lit environment. You don't feel one experience as millions of times brighter than the other. This is because vision (as much of perception) is not proportional: seeing twice as many photons does not produce a sensation of seeing twice as bright a light. The visual system tunes into the current experience by favoring a range of contrast values that is most informative in that environment (Gardner et al., 2005). This is the concept of **contrast gain**: the visual system determines the mean contrast in a scene and represents values around that mean contrast best, while ignoring smaller contrast differences. (See the Outside Resources section for a demonstration.)

The Reconstruction Process

What happens once information leaves your eyes and enters the brain? Neurons project first into the thalamus, in a section known as the lateral geniculate nucleus. The information then splits and projects towards two different parts of the brain. Most of the computations regarding reflexive eye movements are computed in subcortical regions, the evolutionarily older part of the brain. Reflexive eye movements allow you to quickly orient your eyes towards areas of interest and to track objects as they move. The more complex computations, those that eventually allow you to have a visual experience of the world, all happen in the cortex, the evolutionarily newer region of the brain. The first stop in the cortex is at the **primary visual cortex** (also known as V1). Here, the "reconstruction" process begins in earnest: based on the contrast information arriving from the eyes, neurons will start computing information about color and simple lines, detecting various orientations and thicknesses. Small-scale motion signals are also computed (Hubel & Wiesel, 1962).

As information begins to flow towards other "higher" areas of the system, more complex computations are performed. For example, edges are assigned to the object to which they belong, backgrounds are separated from foregrounds, colors are assigned to surfaces, and the global motion of objects is computed. Many of these computations occur in specialized brain areas. For instance, an area called MT processes global-motion information; the parahippocampal place area identifies locations and scenes; the fusiform face area specializes in identifying objects for which fine discriminations are required, like faces. There is even a brain region specialized in letter and word processing. These visual-recognition areas are located along the *ventral pathway* of the brain (also known as the What pathway). Other brain regions along the *dorsal pathway* (or Where-and-How pathway) will compute information about self- and object-motion, allowing you to interact with objects, navigate the environment, and avoid obstacles (Goodale and Milner, 1992).

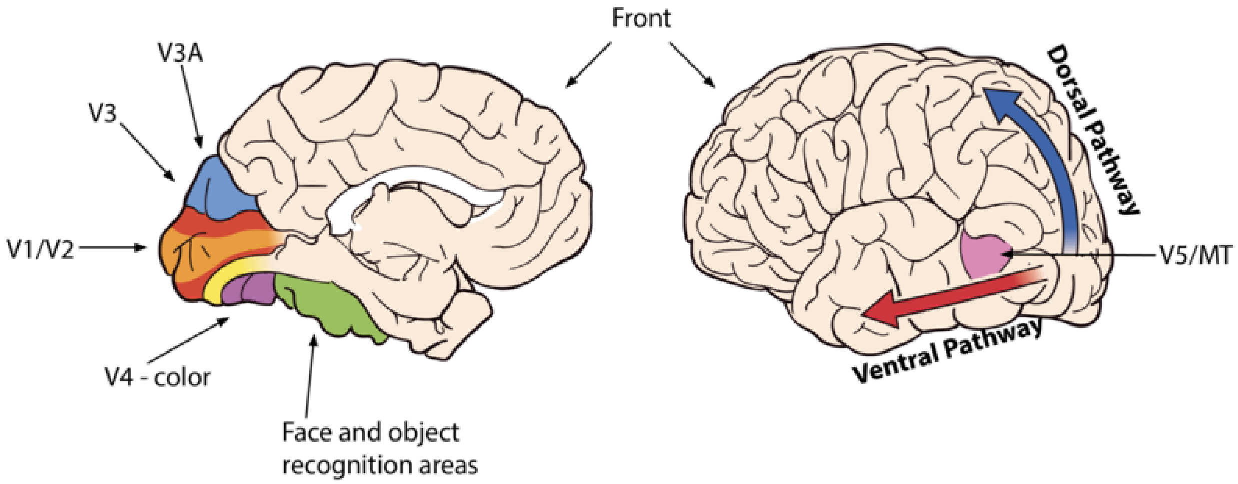

Figure 2: Areas of the brain

Now that you have a basic understanding of how your visual system works, you can ask yourself the question: why do you have two eyes? Everything that we discussed so far could be computed with information coming from a single eye. So why two? Looking at the animal kingdom gives us a clue. Animals who tend to be prey have eyes located on opposite sides of their skull. This allows them to detect predators whenever one appears anywhere around them. Humans, like most predators, have two eyes pointing in the same direction, encoding almost the exact scene twice. This redundancy gives us a binocular advantage: having two eyes not only provides you with two chances at catching a signal in front of you, but the minute difference in perspective that you get from each eye is used by your brain to reconstruct the sense of three-dimensional space. You can get an estimate of how far distant objects are from you, their size, and their volume. This is no easy feat: the signal in each eye is a two-dimensional projection of the world, like two separate pictures drawn upon your retinae. Yet, your brain effortlessly provides you with a sense of depth by combining those two signals. This 3-D reconstruction process also relies heavily on all the knowledge you acquired through experience about spatial information. For instance, your visual system learns to interpret how the volume, distance, and size of objects change as they move closer or farther from you. (See the Outside Resources section for demonstrations.)

The Experience of Color

Perhaps one of the most beautiful aspects of vision is the richness of the color experience that it provides us. One of the challenges that we have as scientists is to understand why the human color experience is what it is. Perhaps you have heard that dogs only have 2 types of color photoreceptors, whereas humans have 3, chickens have 4, and mantis shrimp have 16. Why is there such variation across species? Scientists believe each species has evolved with different needs and uses color perception to signal information about food, reproduction, and health that are unique to their species. For example, humans have a specific sensitivity that allows you to detect slight changes in skin tone. You can tell when someone is embarrassed, aroused, or ill. Detecting these subtle signals is adaptive in a social species like ours.

How is color coded in the brain? The two leading theories of color perception were proposed in the mid-19th century, about 100 years before physiological evidence was found to corroborate them both (Svaetichin, 1956). **Trichromacy theory**, proposed by Young (1802) and Helmholtz (1867), proposed that the eye had three different types of color-sensitive cells based on the observation that any one color can be reproduced by combining lights from three lamps of different hue. If you can adjust separately the intensity of each light, at some point you will find the right combination of the three lights to match any color in the world. This principle is used today on TVs, computer screens, and any colored display. If you look closely enough at a pixel, you will find that it is composed of a blue, a red, and a green light, of varying intensities. Regarding the retina, humans have three types of cones: S-cones, M-cones, and L-cones (also known as blue, green, and red cones, respectively) that are sensitive to three different wavelengths of light.

Around the same time, Hering made a puzzling discovery: some colors are impossible to create. Whereas you can make yellowish greens, bluish reds, greenish blues, and reddish yellows by combining two colors, you can never make a reddish green or a bluish yellow. This observation led Hering (1892) to propose the **Opponent Process theory of color**: color is coded via three opponent channels (red-green, blue-yellow, and black-white). Within each channel, a comparison is constantly computed between the two elements in the pair. In other words, colors are encoded as *differences* between two hues and not as simple combinations of hues. Again, what matters to the brain is *contrast*. When one element is stronger than the other, the stronger color is perceived and the weaker one is suppressed. You can experience this phenomenon by following the link below.

http://nobaproject.com/assets/modules/module-visio...

When both colors in a pair are present to equal extents, the color perception is canceled and we perceive a level of grey. This is why you cannot see a reddish green or a bluish yellow: they cancel each other out. By the way, if you are wondering where the yellow signal comes from, it turns out that it is computed by averaging the M- and L-cone signals. Are these colors uniquely human colors? Some think that they are: the red-green contrast, for example, is finely tuned to detect changes in human skin tone so you can tell when someone blushes or becomes pale. So, the next time you go out for a walk with your dog, look at the sunset and ask yourself, what color does my dog see? Probably none of the orange hues you do!

So now, you can ask yourself the question: do all humans experience color in the same way? Color-blind people, as you can imagine, do not see all the colors that the rest of us see, and this is due to the fact that they lack one (or more) cones in their retina. Incidentally, there are a few women who actually have four different sets of cones in their eyes, and recent research suggests that their experience of color can be (but not always is) richer than the one from three-coned people. A slightly different question, though, is whether all three-coned people have the same internal experiences of colors: is the red inside your head the same red inside your mom's head? That is an almost impossible question to answer that has been debated by philosophers for millennia, yet recent data suggests that there might in fact be cultural differences in the way we perceive color. As it turns out, not all cultures categorize colors in the same way, for example. And some groups "see" different shades of what we in the Western world would call the "same" color, as categorically different colors. The Berinmo tribe in New Guinea, for instance, appear to experience green shades that denote leaves that are alive as belonging to an entirely different color category than the sort of green shades that denote dying leaves. Russians, too, appear to experience light and dark shades of blue as different categories of colors, in a way that most Westerners do not. Further, current brain imaging research suggests that people's brains change (increase in white-matter volume) when they learn new color categories! These are intriguing and suggestive findings, for certain, that seem to indicate that our cultural environment may in fact have some (small) but definite impact on how people use and experience colors across the globe.

Integration with Other Modalities

Vision is not an encapsulated system. It interacts with and depends on other sensory modalities. For example, when you move your head in one direction, your eyes reflexively move in the opposite direction to compensate, allowing you to maintain your gaze on the object that you are looking at. This reflex is called the **vestibulo-ocular reflex**. It is achieved by integrating information from both the visual and the vestibular system (which knows about body motion and position). You can experience this compensation quite simply. First, while you keep your head still and your gaze looking straight ahead, wave your finger in front of you from side to side. Notice how the image of the finger appears blurry. Now, keep your finger steady and look at it while you move your head from side to side. Notice how your eyes reflexively move to compensate the movement of your head and how the image of the finger stays sharp and stable. Vision also interacts with your proprioceptive system, to help you find where all your body parts are, and with your auditory system, to help you understand the sounds people make when they speak. You can learn more about this in the Noba module about multimodal perception (**http://noba.to/cezw4qyn**).

Finally, vision is also often implicated in a blending-of-sensations phenomenon known as **synesthesia**. Synesthesia occurs when one sensory signal gives rise to two or more sensations. The most common type is *grapheme-color* synesthesia. About 1 in 200 individuals experience a sensation of color associated with specific letters, numbers, or words: the number 1 might always be seen as red, the number 2 as orange, etc. But the more fascinating forms of synesthesia blend sensations from entirely different sensory modalities, like taste and color or music and color: the taste of chicken might elicit a sensation of green, for example, and the timbre of violin a deep purple.

Concluding Remarks

We are at an exciting moment in our scientific understanding of vision. We have just begun to get a functional understanding of the visual system. It is not sufficiently evolved for us to recreate artificial visual systems (i.e., we still cannot make robots that “see” and understand light signals as we do), but we are getting there. Just recently, major breakthroughs in vision science have allowed researchers to significantly improve retinal prosthetics: photosensitive circuits that can be implanted on the back of the eyeball of blind people that connect to visual areas of the brain and have the capacity to partially restore a “visual experience” to these patients (Nirenberg & Pandarinath, 2012). And using functional magnetic brain imaging, we can now “decode” from your brain activity the images that you saw in your dreams while you were asleep (Horikawa, Tamaki, Miyawaki, & Kamitani, 2013)! Yet, there is still so much more to understand. Consider this: if vision is a construction process that takes time, whatever we see *now* is no longer what is front of us. Yet, humans can do amazing time-sensitive feats like hitting a 90-mph fastball in a baseball game. It appears then that a fundamental function of vision is not just to know what is happening around you now, but actually to make an accurate inference about what you are about to see *next* (Enns & Lleras, 2008), so that you can keep up with the world. Understanding how this future-oriented, *predictive* function of vision is achieved in the brain is probably the next big challenge in this fascinating realm of research.

Outside Resources

Video: Acquired knowledge and its impact on our three-dimensional interpretation of the world - 3D Street Art
http://www.youtube.com/watch?v=GwNeukAmxJw

Video: Acquired knowledge and its impact on our three-dimensional interpretation of the world - Anamorphic Illusions
http://www.youtube.com/watch?v=tBNHPk-Lnkk

Video: Acquired knowledge and its impact on our three-dimensional interpretation of the world - Optical Illusion
http://www.youtube.com/watch?v=YjmHofJ2da0&feature=related

Web: Amazing library with visual phenomena and optical illusions, explained
http://michaelbach.de/ot/index.html

Web: Anatomy of the eye
http://www.eyecareamerica.org/eyecare/anatomy/

Web: Demonstration of contrast gain adaptation
http://www.michaelbach.de/ot/lum_contrast-adapt/

Web: Demonstration of illusory contours and lateral inhibition. Mach bands
http://michaelbach.de/ot/lum-MachBands/index.html

Web: Demonstration of illusory contrast and lateral inhibition. The Hermann grid
http://michaelbach.de/ot/lum_herGrid/

Web: Further information regarding what and where/how pathways
http://www.scholarpedia.org/article/What_and_where_pathways

Discussion Questions

1. When running in the dark, it is recommended that you never look straight at the ground. Why? What would be a better strategy to avoid obstacles?

2. The majority of ganglion cells in the eye specialize in detecting drops in the amount of light coming from a given location. That is, they increase their firing rate when they detect less light coming from a specific location. Why might the absence of light be more important than the presence of light? Why would it be evolutionarily advantageous to code this type of information?
3. There is a hole in each one of your eyeballs called the optic disk. This is where veins enter the eyeball and where neurons (the axons of the ganglion cells) exit the eyeball. Why do you not see two holes in the world all the time? Close one eye now. Why do you not see a hole in the world now? To "experience" a blind spot, follow the instructions in this website: http://michaelbach.de/ot/cog_blindSpot/index.html
4. Imagine you were given the task of testing the color-perception abilities of a newly discovered species of monkeys in the South Pacific. How would you go about it?
5. An important aspect of emotions is that we sense them in ourselves much in the same way as we sense other perceptions like vision. Can you think of an example where the concept of contrast gain can be used to understand people's responses to emotional events?

Vocabulary

Binocular advantage
Benefits from having two eyes as opposed to a single eye.

Cones
Photoreceptors that operate in lighted environments and can encode fine visual details. There are three different kinds (S or blue, M or green and L or red) that are each sensitive to slightly different types of light. Combined, these three types of cones allow you to have color vision.

Contrast
Relative difference in the amount and type of light coming from two nearby locations.

Contrast gain
Process where the sensitivity of your visual system can be tuned to be most sensitive to the levels of contrast that are most prevalent in the environment.

Dark adaptation
Process that allows you to become sensitive to very small levels of light, so that you can actually see in the near-absence of light.

Lateral inhibition
A signal produced by a neuron aimed at suppressing the response of nearby neurons.

Opponent Process Theory
Theory of color vision that assumes there are four different basic colors, organized into two pairs (red/green and blue/yellow) and proposes that colors in the world are encoded in terms of the opponency (or difference) between the colors in each pair. There is an additional black/white pair responsible for coding light contrast.

Photoactivation
A photochemical reaction that occurs when light hits photoreceptors, producing a neural signal.

Primary visual cortex (V1)
Brain region located in the occipital cortex (toward the back of the head) responsible for processing basic visual information like the detection, thickness, and orientation of simple lines, color, and small-scale motion.

Rods
Photoreceptors that are very sensitive to light and are mostly responsible for night vision.

Synesthesia
The blending of two or more sensory experiences, or the automatic activation of a secondary (indirect) sensory experience due to certain aspects of the primary (direct) sensory stimulation.

Trichromacy theory
Theory that proposes that all of your color perception is fundamentally based on the combination of three (not two, not four) different color signals.

Vestibulo-ocular reflex
Coordination of motion information with visual information that allows you to maintain your gaze on an object while you move.

What pathway
Pathway of neural processing in the brain that is responsible for your ability to recognize what is around you.

Where-and-How pathway
Pathway of neural processing in the brain that is responsible for you knowing where things are in the world and how to interact with them.

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5

Attention

Frances Friedrich

We use the term “attention“ all the time, but what processes or abilities does that concept really refer to? This module will focus on how attention allows us to select certain parts of our environment and ignore other parts, and what happens to the ignored information. A key concept is the idea that we are limited in how much we can do at any one time. So we will also consider what happens when someone tries to do several things at once, such as driving while using electronic devices.

Learning Objectives

- Understand why selective attention is important and how it can be studied.
- Learn about different models of when and how selection can occur.
- Understand how divided attention or multitasking is studied, and implications of multitasking in situations such as distracted driving.

What is Attention?

Before we begin exploring attention in its various forms, take a moment to consider how you think about the concept. How would you define attention, or how do you use the term? We certainly use the word very frequently in our everyday language: “ATTENTION! USE ONLY AS DIRECTED!” warns the label on the medicine bottle, meaning be alert to possible danger. “Pay attention!” pleads the weary seventh-grade teacher, not warning about danger (with possible exceptions, depending on the teacher) but urging the students to focus on the task at hand.

We may refer to a child who is easily distracted as having an attention disorder, although we also are told that Americans have an attention span of about 8 seconds, down from 12 seconds in 2000, suggesting that we *all* have trouble sustaining concentration for any amount of time (from **www.Statisticbrain.com).** How that number was determined is not clear from the Web site, nor is it clear how attention span in the goldfish—9 seconds!—was measured, but the fact that our average span reportedly is less than that of a goldfish is intriguing, to say the least.

William James wrote extensively about attention in the late 1800s. An often quoted passage (James, 1890/1983) beautifully captures how intuitively obvious the concept of attention is, while it remains very difficult to define in measurable, concrete terms:

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others. (pp. 381–382)

Are you reading these words right here right now? If so, it’s only because you directed your attention toward them. [Image: CC BY 2.0, https://goo.gl/BRvSA7]

Notice that this description touches on the conscious nature of attention, as well as the notion that what is in consciousness is often controlled voluntarily but can also be determined by events that capture our attention. Implied in this description is the idea that we seem to have a limited capacity for information processing, and that we can only attend to or be consciously aware of a small amount of information at any given time.

Many aspects of attention have been studied in the field of psychology. In some respects, we define different types of attention by the nature of the task used to study it. For example, a crucial issue in World War II was how long an individual could remain highly alert and accurate while watching a radar screen for enemy planes, and this problem led psychologists to study how attention works under such conditions. When watching for a rare event, it is easy to allow concentration to lag. (This a continues to be a challenge today for TSA agents, charged with looking at images of the contents of your carry-on items in search of knives, guns, or shampoo bottles larger than 3 oz.) Attention in the context of this type of search task refers to the level of *sustained attention* or *vigilance* one can maintain. In contrast, divided attention tasks allow us to determine how well individuals can attend to many sources of information at once. *Spatial attention* refers specifically to how we focus on one part of our environment and how we move attention to other locations in the environment. These are all examples of different aspects of attention, but an implied element of most of these ideas is the concept of selective attention; some information is attended to while other information is intentionally blocked out. This module will focus on important issues in selective and divided attention, addressing these questions:

- Can we pay attention to several sources of information at once, or do we have a limited capacity for information?
- How do we select what to pay attention to?
- What happens to information that we try to ignore?
- Can we learn to divide attention between multiple tasks?

Selective Attention

The Cocktail Party

Selective attention is *the ability to select certain stimuli in the environment to process, while ignoring distracting information*. One way to get an intuitive sense of how attention works is to consider situations in which attention is used. A party provides an excellent example for our purposes. Many people may be milling around, there is a dazzling variety of colors and sounds and smells, the buzz of many conversations is striking. There are so many conversations going on; how is it possible to select just one and follow it? You don't have to be looking at the person talking; you may be listening with great interest to some gossip while pretending not to hear. However, once you are engaged in conversation with someone, you quickly become aware that

Beyond just hearing your name from the clamor at a party, other words or concepts, particularly unusual or significant ones to you, can also snag your attention. [Image: Ross, https://goo.gl/TVDfTn, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF] you cannot also listen to other conversations at the same time. You also are probably *not* aware of how tight your shoes feel or of the smell of a nearby flower arrangement. On the other hand, if someone behind you mentions your name, you typically notice it immediately and may start attending to that (much more interesting) conversation. This situation highlights an interesting set of observations. We have an amazing ability to select and track one voice, visual object, etc., even when a million things are competing for our attention, but at the same time, we seem to be limited in how much we can attend to at one time, which in turn suggests that attention is crucial in selecting what is important. How does it all work?

Dichotic Listening Studies

This cocktail party scenario is the quintessential example of selective attention, and it is essentially what some early researchers tried to replicate under controlled laboratory conditions as a starting point for understanding the role of attention in perception (e.g., Cherry, 1953; Moray, 1959). In particular, they used dichotic listening and shadowing tasks to evaluate the selection process. Dichotic listening simply refers to the situation when two messages are presented simultaneously to an individual, with one message in each ear. In order to control which message the person attends to, the individual is asked to repeat back or “shadow” one of the messages as he hears it. For example, let’s say that a story about a camping trip is presented to John’s left ear, and a story about Abe Lincoln is presented to his right ear. The typical dichotic listening task would have John repeat the story presented to one ear as he hears it. Can he do that without being distracted by the information in the other ear?

People can become pretty good at the shadowing task, and they can easily report the content of the message that they attend to. But what happens to the ignored message? Typically, people can tell you if the ignored message was a man’s or a woman’s voice, or other physical characteristics of the speech, but they cannot tell you what the message was about. In fact, many studies have shown that people in a shadowing task were not aware of a change in the language of the message (e.g., from English to German; Cherry, 1953), and they didn't even notice when the same word was repeated in the unattended ear more than 35 times (Moray, 1959)! Only the basic physical characteristics, such as the pitch of the unattended message, could be reported.

On the basis of these types of experiments, it seems that we can answer the first question about how much information we can attend to very easily: not very much. We clearly have a limited capacity for processing information for meaning, making the selection process all the more important. The question becomes: How does this selection process work?

Models of Selective Attention

Broadbent's Filter Model. Many researchers have investigated how selection occurs and what happens to ignored information. Donald Broadbent was one of the first to try to characterize the selection process. His Filter Model was based on the dichotic listening tasks described above as well as other types of experiments (Broadbent, 1958). He found that people select information on the basis of *physical features*: the sensory channel (or ear) that a message was coming in, the pitch of the voice, the color or font of a visual message. People seemed vaguely aware of the physical features of the unattended information, but had no knowledge of the meaning. As a result, Broadbent argued that selection occurs *very early*, with no additional processing for the unselected information. A flowchart of the model might look like this:

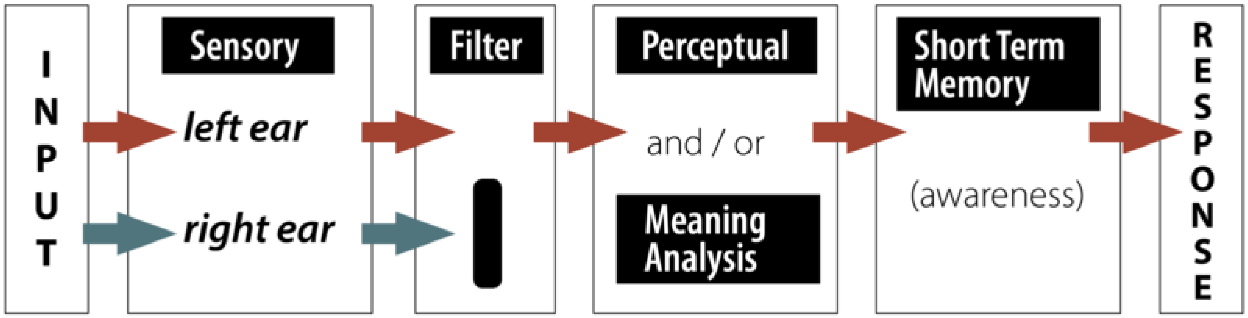


Figure 1: This figure shows information going in both the left and right ears. Some basic sensory information, such as pitch, is processed, but the filter only allows the information from one ear to be processed further. Only the information from the left ear is transferred to short-term memory (STM) and conscious awareness, and then further processed for meaning. That means that the ignored information never makes it beyond a basic physical analysis.

Treisman' s Attenuation Model

Broadbent's model makes sense, but if you think about it you already know that it cannot account for all aspects of the Cocktail Party Effect. What doesn't fit? The fact is that you tend to hear your own name when it is spoken by someone, even if you are deeply engaged in a conversation. We mentioned earlier that people in a shadowing experiment were unaware of a word in the unattended ear that was repeated many times—and yet many people noticed their own name in the unattended ear even it occurred only once.

Anne Treisman (1960) carried out a number of dichotic listening experiments in which she presented two different stories to the two ears. As usual, she asked people to shadowthe message in one ear. As the stories progressed, however, she switched the stories to the opposite ears. Treisman found that individuals spontaneously followed the story, or the content of the message, when it shifted from the left ear to the right ear. Then they realized they were shadowing the wrong ear and switched back.

Results like this, and the fact that you tend to hear meaningful information even when you aren't paying attention to it, suggest that we *do* monitor the unattended information to some degree on the basis of its meaning. Therefore, the filter theory can't be right to suggest that unattended information is completely blocked at the sensory analysis level. Instead, Treisman suggested that selection *starts* at the physical or perceptual level, but that the unattended information is not blocked completely, it is just weakened or *attenuated*. As a result, highly meaningful or pertinent information in the unattended ear will get through the filter for further processing at the level of meaning. The figure below shows information going in both ears, and in this case there is no filter that completely blocks nonselected information. Instead, selection of the left ear information strengthens that material, while the nonselected information in the right ear is weakened. However, if the preliminary analysis shows that the nonselected information is especially pertinent or meaningful (such as your own name), then the Attenuation Control will instead strengthen the more meaningful information.

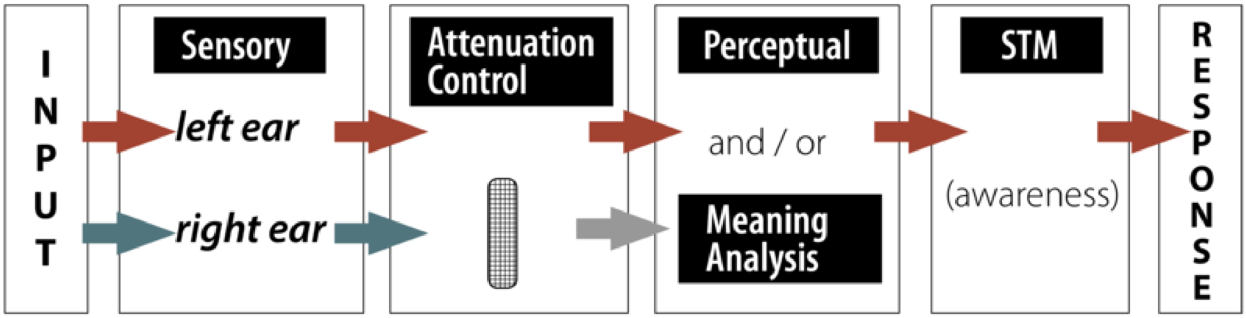


Figure 2

Late Selection Models

Other selective attention models have been proposed as well. A*late selection* or *response selection* model proposed by Deutsch and Deutsch (1963) suggests that all information in the unattended ear is processed on the basis of meaning, not just the selected or highly pertinent information. However, only the information that is relevant for the task response gets into conscious awareness. This model is consistent with ideas of subliminal perception; in other words, that you don't have to be aware of or attending a message for it to be fully processed for meaning.

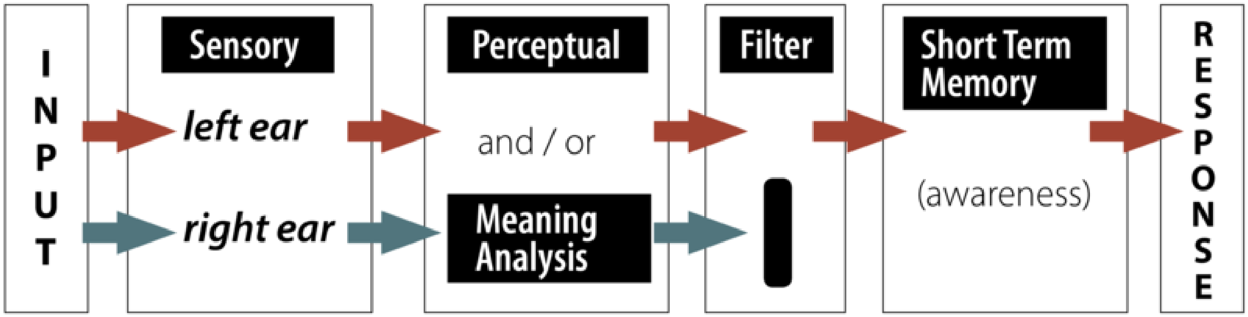


Figure 3

You might notice that this figure looks a lot like that of the Early Selection model—only the location of the selective filter has changed, with the assumption that analysis of meaning occurs *before* selection occurs, but only the selected information becomes conscious.

Multimode Model

Why did researchers keep coming up with different models? Because no model really seemed to account for all the data, some of which indicates that nonselected information is blocked completely, whereas other studies suggest that it can be processed for meaning. The multimode model addresses this apparent inconsistency, suggesting that the stage at which selection occurs can change depending on the task. Johnston and Heinz (1978) demonstrated that under some conditions, we can select what to attend to at a very early stage and we do not process the content of the unattended message very much at all. Analyzing physical information, such as attending to information based on whether it is a male or female voice, is relatively easy; it occurs automatically, rapidly, and doesn't take much effort. Under the right conditions, we can select what to attend to on the basis of the meaning of the messages. However, the late selection option—processing the content of all messages before selection—is more difficult and requires more effort. The benefit, though, is that we have the flexibility to change how we deploy our attention depending upon what we are trying to accomplish, which is one of the greatest strengths of our cognitive system.

This discussion of selective attention has focused on experiments using auditory material, but the same principles hold for other perceptual systems as well. Neisser (1979) investigated some of the same questions with visual materials by superimposing two semi-transparent video clips and asking viewers to attend to just one series of actions. As with the auditory materials, viewers often were unaware of what went on in the other clearly visible video. Twenty years later, Simons and Chabris (1999) explored and expanded these findings using similar techniques, and triggered a flood of new work in an area referred to as inattentional blindness. We touch on those ideas below, and you can also refer to another Noba Module, **Failures of Awareness: The Case of Inattentional Blindness** for a more complete discussion.

Focus Topic 1: Subliminal Perception

The idea of subliminal perception—that stimuli presented below the threshold for awareness can influence thoughts, feelings, or actions—is a fascinating and kind of creepy one. Can messages you are unaware of, embedded in movies or ads or the music playing in the grocery store, really influence what you buy? Many such claims of the power of subliminal perception have been made. One of the most famous came from a market researcher who claimed that the message "Eat Popcorn" briefly flashed throughout a movie increased popcorn sales by more than 50%, although he later admitted that the study was made up (Merikle, 2000). Psychologists have worked hard to investigate whether this is a valid phenomenon. Studying subliminal perception is more difficult than it might seem, because of the difficulty of establishing what the threshold for consciousness is or of even determining what type of threshold is important; for example, Cheesman and Merikle (1984, 1986) make an important distinction between objective and subjective thresholds. The bottom line is that there is some evidence that individuals can be influenced by stimuli they are not aware of, but how complex the stimuli can be or the extent to which unconscious material can affect behavior is not settled (e.g., Bargh & Morsella, 2008; Greenwald, 1992; Merikle, 2000).

Divided Attention and Multitasking

In spite of the evidence of our limited capacity, we all like to think that we can do several things at once. Some people claim to be able to multitask without any problem: reading a textbook while watching television and talking with friends; talking on the phone while playing computer games; texting while driving. The fact is that we sometimes can *seem* to juggle several things at once, but the question remains whether dividing attention in this way impairs performance.

Is it possible to overcome the limited capacity that we experience when engaging in cognitive tasks? We know that with extensive practice, we can acquire skills that do not appear to require conscious attention. As we walk down the street, we don't need to think consciously about what muscle to contract in order to take the next step. Indeed, paying attention to automated skills can lead to a breakdown in performance, or "choking" (e.g., Beilock & Carr, 2001). But what about higher level, more mentally demanding tasks: Is it possible to learn to perform two complex tasks at the same time?

Divided Attention Tasks

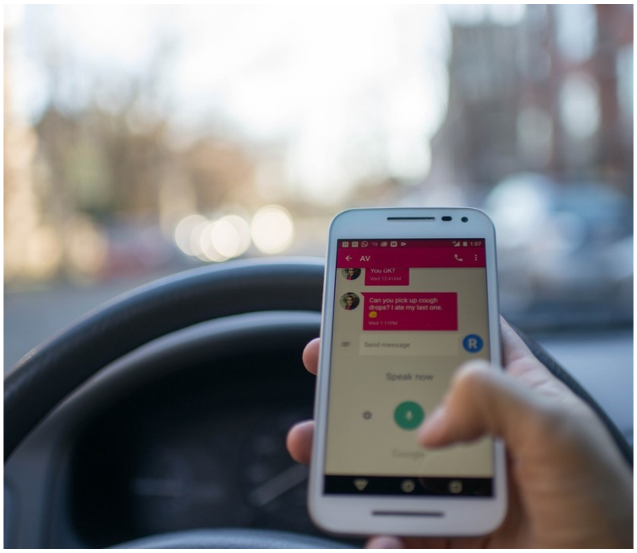
Unless a task is fully automated, some researchers suggest that "multi-tasking" doesn't really exist; you are just rapidly switching your attention back and forth between tasks. [Image: CC0 Public Domain, https://goo.gl/m25gce]

In a classic study that examined this type of divided attention task, two participants were trained to take dictation for spoken words while reading unrelated material for comprehension (Spelke, Hirst, & Neisser, 1976). In divided attention tasks such as these, each task is evaluated separately, in order to determine baseline performance when the individual can allocate as many cognitive resources as necessary to one task at a time. Then performance is evaluated when the two tasks are performed simultaneously. A decrease in performance for either task would suggest that even if attention can be divided or switched between the tasks, the cognitive demands are too great to avoid disruption of performance. (We should note here that divided attention tasks are designed, in principle, to see if two tasks can be carried out simultaneously. A related research area looks at *task switching* and how well we can switch back and forth among different tasks [e.g., Monsell, 2003]. It turns out that switching itself is cognitively demanding and can impair performance.)

The focus of the Spelke et al. (1976) study was whether individuals could learn to perform two relatively complex tasks concurrently, without impairing performance. The participants received plenty of practice—the study lasted 17 weeks and they had a 1-hour session each day, 5 days a week. These participants were able to learn to take dictation for lists of words and read for comprehension without affecting performance in either task, and the authors suggested that perhaps there are not fixed limits on our attentional capacity. However, changing the tasks somewhat, such as reading aloud rather than silently, impaired performance initially, so this multitasking ability may be specific to these well-learned tasks. Indeed, not everyone could learn to perform two complex tasks without performance costs (Hirst, Neisser, & Spelke, 1978), although the fact that some can is impressive.

Distracted Driving

More relevant to our current lifestyles are questions about multitasking while texting or having cell phone conversations. Research designed to investigate, under controlled conditions, multitasking while driving has revealed some surprising results. Certainly there are many possible types of distractions that could impair driving performance, such as applying makeup using the rearview mirror, attempting (usually in vain) to stop the kids in the backseat from fighting, fiddling with the CD player, trying to negotiate a handheld cell phone, a cigarette, and a soda all at once, eating a bowl of cereal while driving (!). But we tend to have a strong sense that we CAN multitask while driving, and cars are being built with more and more technological capabilities that encourage multitasking. How good are we at dividing attention in these cases?



If you look at your phone for just 5 seconds while driving at 55mph, that means you have driven the length of a football field without looking at the road. [Image: CC0 Public Domain, https://goo.gl/m25gce]

Most people acknowledge the distraction caused by texting while driving and the reason seems obvious: Your eyes are off the road and your hands and at least one hand (often both) are engaged while texting. However, the problem is not simply one of occupied hands or eyes, but rather that the *cognitive* demands on our limited capacity systems can seriously impair driving performance (Strayer, Watson, & Drews, 2011). The effect of a cell phone conversation on performance (such as not noticing someone's brake lights or responding more slowly to them) is just as significant when the individual is having a conversation with a hands-free device as with a handheld phone; the same impairments do not occur when listening to the radio or a book on tape (Strayer & Johnston, 2001). Moreover, studies using eye-tracking devices have shown that drivers are less likely to later recognize objects that they *did* look at when using a cell phone while driving (Strayer & Drews, 2007). These findings demonstrate that cognitive distractions such as cell phone conversations can produce inattentional blindness, or a lack of awareness of what is right before your eyes (see also, Simons & Chabris, 1999). Sadly, although we all like to think that we can multitask while driving, in fact the percentage of people who can truly perform cognitive tasks without impairing their driving performance is estimated to be about 2% (Watson & Strayer, 2010).

Summary

It may be useful to think of attention as a mental resource, one that is needed to focus on and fully process important information, especially when there is a lot of distracting “noise” threatening to obscure the message. Our selective attention system allows us to find or track an object or conversation in the midst of distractions. Whether the selection process occurs early or late in the analysis of those events has been the focus of considerable research, and in fact how selection occurs may very well depend on the specific conditions. With respect to divided attention, in general we can only perform one cognitively demanding task at a time, and we may not even be aware of unattended events even though they might seem too obvious to miss (check out some examples in the Outside Resources below). This type of inattention blindness can occur even in well-learned tasks, such as driving while talking on a cell phone. Understanding how attention works is clearly important, even for our everyday lives.

Outside Resources

Video: Here's a wild example of how much we fail to notice when our attention is captured by one element of a scene.
http://www.youtube.com/watch?v=ubNF9QNEQLA&feature=related

Video: Try this test to see how well you can focus on a task in the face of a lot of distraction.
http://www.youtube.com/watch?v=Ahg6qcgoay4&NR=1

Discussion Questions

1. Discuss the implications of the different models of selective attention for everyday life. For instance, what advantages and disadvantages would be associated with being able to filter out all unwanted information at a very early stage in processing? What are the implications of processing all ignored information fully, even if you aren't consciously aware of that information?
2. Think of examples of when you feel you can successfully multitask and when you can’t. Discuss what aspects of the tasks or the situation seem to influence divided attention performance. How accurate do you think you are in judging your own multitasking ability?
3. What are the public policy implications of current evidence of inattentional blindness as a result of distracted driving? Should this evidence influence traffic safety laws? What additional studies of distracted driving would you propose?

Vocabulary

Dichotic listening
An experimental task in which two messages are presented to different ears.

Divided attention
The ability to flexibly allocate attentional resources between two or more concurrent tasks.

Inattentional blindness
The failure to notice a fully visible object when attention is devoted to something else.

Limited capacity
The notion that humans have limited mental resources that can be used at a given time.

Selective attention
The ability to select certain stimuli in the environment to process, while ignoring distracting information.

Shadowing
A task in which the individual is asked to repeat an auditory message as it is presented.

Subliminal perception
The ability to process information for meaning when the individual is not consciously aware of that information.

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6

Failures of Awareness: The Case of Inattentional Blindness

Daniel Simons

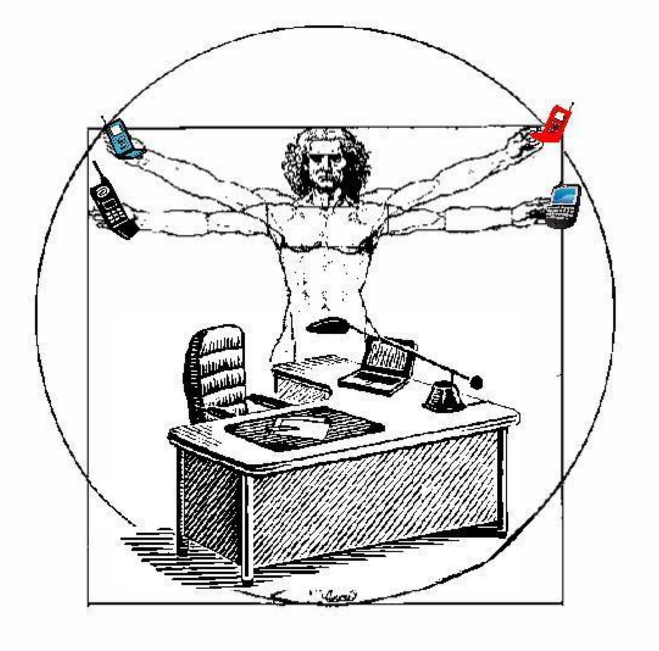
We think important objects and events in our world will automatically grab our attention, but they often don't, particularly when our attention is focused on something else. The failure to notice unexpected objects or events when attention is focused elsewhere is now known as inattentional blindness. The study of such failures of awareness has a long history, but their practical importance has received increasing attention over the past decade. This module describes the history and status of research on inattentional blindness, discusses the reasons why we find these results to be counterintuitive, and the implications of failures of awareness for how we see and act in our world.

Learning Objectives

- Learn about inattentional blindness and why it occurs.
- Identify ways in which failures of awareness are counterintuitive.
- Better understand the link between focused attention and failures of awareness.

Do you regularly spot editing errors in movies? Can you multitask effectively, texting while talking with your friends or watching television? Are you fully aware of your surroundings? If you answered yes to any of those questions, you're not alone. And, you're most likely wrong.

More than 50 years ago, experimental psychologists began documenting the many ways that our perception of the world is limited, not by our eyes and ears, but by our minds. We appear able to process only one stream of information at a time, effectively filtering other information from awareness. To a large extent, we perceive only that which receives the focus of our cognitive efforts: our attention.



Some researchers contend that there really is no such thing as multi-tasking. Instead, people are just rapidly switching their attention between tasks, rather than holding those tasks in their attention at the same time. [Image: Mike Licht, https://goo.gl/z7rkve, CC BY 2.0, https://goo.gl/v4Y0Zv]

Imagine the following task, known as **dichotic listening** (e.g., Cherry, 1953; Moray, 1959; Treisman, 1960): You put on a set of headphones that play two completely different speech streams, one to your left ear and one to your right ear. Your task is to repeat each syllable spoken into your left ear as quickly and accurately as possible, mimicking each sound as you hear it. When performing this attention-demanding task, you won't notice if the speaker in your right ear switches to a different language or is replaced by a different speaker with a similar voice. You won't notice if the content of their speech becomes nonsensical. In effect, you are deaf to the substance of the ignored speech. But, that is not because of the limits of your auditory senses. It is a form of cognitive deafness, due to the nature of focused, selective attention. Even if the speaker on your right headphone says your name, you will notice it only about one-third of the time (Conway, Cowan, & Bunting, 2001). And, at least by some accounts, you only notice it that often because you still devote some of your limited attention to the ignored speech stream (Holendar, 1986). In this task, you will tend to notice only large physical changes (e.g., a switch from a male to a female speaker), but not substantive ones, except in rare cases.

This **selective listening** task highlights the power of attention to filter extraneous information from awareness while letting in only those elements of our world that we want to hear. Focused attention is crucial to our powers of observation, making it possible for us to zero in on what we want to see or hear while filtering out irrelevant distractions. But, it has consequences as well: We can miss what would otherwise be obvious and important signals.

The same pattern holds for vision. In a groundbreaking series of studies in the 1970s and early 1980s, Neisser and his colleagues devised a visual analogue of the dichotic listening task (Neisser & Becklen, 1975). Their subjects viewed a video of two distinct, but partially transparent and overlapping, events. For example, one event might involve two people playing a hand-clapping game and the other might show people passing a ball. Because the two events were partially transparent and overlapping, both produced sensory signals on the retina regardless of which event received the participant's attention. When participants were asked to monitor one of the events by counting the number of times the actors performed an action (e.g., hand clapping or completed passes), they often failed to notice unexpected events in the ignored video stream (e.g., the hand-clapping players stopping their game and shaking hands). As for dichotic listening, the participants were unaware of events happening outside the focus of their attention, even when looking right at them. They could tell that other "stuff" was happening on the screen, but many were unaware of the meaning or substance of that stuff.

To test the power of selective attention to induce failures of awareness, Neisser and colleagues (Neisser, 1979) designed a variant of this task in which participants watched a video of two teams of players, one wearing white shirts and one wearing black shirts. Subjects were asked to press a key whenever the players in white successfully passed a ball, but to ignore the players in black. As for the other videos, the teams were filmed separately and then superimposed so that they literally occupied the same space (they were partially transparent). Partway through the video, a person wearing a raincoat and carrying an umbrella strolled through the scene. People were so intently focused on spotting passes that they often missed the "umbrella woman." (Pro tip: If you look closely at the video, you'll see that Ulric Neisser plays on both the black and white teams.)

Have you ever been paying attention to something so closely you missed another event in the background? Or have you ever been so used to seeing something a certain way that when it changed, you didn't even notice it had? [Image: Tilde Ann Thurium, https://goo.gl/pb8I6Q, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

These surprising findings were well known in the field, but for decades, researchers dismissed their implications because the displays had such an odd, ghostly appearance. Of course, we would notice if the displays were fully opaque and vivid rather than partly transparent and grainy. Surprisingly, no studies were built on Neisser's method for nearly 20 years. Inspired by these counterintuitive findings and after discussing them with Neisser himself, Christopher Chabris and I revisited them in the late 1990s (Simons & Chabris, 1999). We replicated Neisser's work, again finding that many people missed the umbrella woman when all of the actors in the video were partially transparent and occupying the same space. But, we added another wrinkle: a version of the video in which all of the actions of both teams of players were choreographed and filmed with a single camera. The players moved in and around each other and were fully visible. In the most dramatic version, we had a woman in a gorilla suit walk into the scene, stop to face the camera, thump her chest, and then walk off the other side after nine seconds on screen. Fully half the observers missed the gorilla when counting passes by the team in white.

This phenomenon is now known as inattentional blindness, the surprising failure to notice an unexpected object or event when attention is focused on something else (Mack & Rock, 1998). The past 15 years has seen a surge of interest in such failures of awareness, and we now have a better handle on the factors that cause people to miss unexpected events as well as the range of situations in which inattentional blindness occurs. People are much more likely to notice unexpected objects that share features with the attended items in a display (Most et al., 2001). For example, if you count passes by the players wearing black, you are more likely to notice the gorilla than if you count passes by the players wearing white because the color of the gorilla more closely matches that of the black-shirted players (Simons & Chabris, 1999). However, even unique items can go unnoticed. In one task, people monitored black shapes and ignored white shapes that moved around a computer window (Most et al., 2001). Approximately 30 percent of them failed to detect the bright red cross traversing the display, even though it was the only colored item and was visible for five seconds.

The more effort a cognitive task requires the more likely it becomes that you'll miss noticing something significant. [Image: CC0 Public Domain, https://goo.gl/m25gce]

Another crucial influence on noticing is the effort you put into the attention-demanding task. If you have to keep separate counts of bounce passes and aerial passes, you are less likely to notice the gorilla (Simons & Chabris, 1999), and if you are tracking faster moving objects, you are less likely to notice (Simons & Jensen, 2009). You can even miss unexpected visual objects when you devote your limited cognitive resources to a memory task (Fougnie & Marois, 2007), so the limits are not purely visual. Instead, they appear to reflect limits on the capacity of attention. Without attention to the unexpected event, you are unlikely to become aware of it (Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005).

Inattentional blindness is not just a laboratory curiosity—it also occurs in the real world and under more natural conditions. In a recent study (Chabris, Weinberger, Fontaine, & Simons, 2011), Chabris and colleagues simulated a famous police misconduct case in which a Boston police officer was convicted of lying because he claimed not to have seen a brutal beating (Lehr, 2009). At the time, he had been chasing a murder suspect and ran right past the scene of a brutal assault. In Chabris' simulation, subjects jogged behind an experimenter who ran right past a simulated fight scene. At night, 65 percent missed the fight scene. Even during broad daylight, 44 percent of observers jogged right passed it without noticing, lending some plausibility to the Boston cop's story that he was telling the truth and never saw the beating.

Perhaps more importantly, auditory distractions can induce real-world failures to see. Although people believe they can multitask, few can. And, talking on a phone while driving or walking decreases situation awareness and increases the chances that people will miss something important (Strayer & Johnston, 2001). In a dramatic illustration of cell phone–induced inattentional blindness, Ira Hymen observed that people talking on a cell phone as they walked across a college campus were less likely than other pedestrians to notice a unicycling clown who rode across their path (Hyman, Boss, Wise, McKenzie, & Caggiano, 2011).

Recently, the study of this sort of awareness failure has returned to its roots in studies of listening, with studies documenting **inattentional deafness**: When listening to a set of spatially localized conversations over headphones, people often fail to notice the voice of a person walking through the scene repeatedly stating "I am a gorilla" (Dalton & Fraenkel, 2012). Under conditions of focused attention, we see and hear far less of the unattended information than we might expect (Macdonald & Lavie, 2011; Wayand, Levin, & Varakin, 2005).

We now have a good understanding of the ways in which focused attention affects the detection of unexpected objects falling outside that focus. The greater the demands on attention, the less likely people are to notice objects falling outside their attention (Macdonald & Lavie, 2011; Simons & Chabris, 1999; Simons & Jensen, 2009). The more like the ignored elements of a scene, the less likely people are to notice. And, the more distracted we are, the less likely we are to be aware of our surroundings. Under conditions of distraction, we effectively develop tunnel vision.

Now you see me, now you don't! Although the research on attention has only developed over the last few decades, magicians have been taking advantages of our susceptibility to misguided focus for centuries. [Image: ShahanB, https://goo.gl/p5DYXH, CC BY-SA 3.0, https://goo.gl/eLCn2O]

Despite this growing understanding of the limits of attention and the factors that lead to more or less noticing, we have relatively less understanding of individual differences in noticing (Simons & Jensen, 2009). Do some people consistently notice the unexpected while others are obliviously unaware of their surroundings? Or, are we all subject to inattentional blindness due to structural limits on the nature of attention? The question remains controversial. A few studies suggest that those people who have a greater working memory capacity are more likely to notice unexpected objects (Hannon & Richards, 2010; Richards, Hannon, & Derakshan, 2010). In effect, those who have more resources available when focusing attention are more likely to spot other aspects of their world. However, other studies find no such relationship: Those with greater working memory capacity are not any more likely to spot an unexpected object or event (Seegmiller, Watson, & Strayer, 2011; Bredemeier & Simons, 2012). There are theoretical reasons to predict each pattern. With more resources available, people should be more likely to notice (see Macdonald & Lavie, 2011). However, people with greater working memory capacity also tend to be better able to maintain their focus on their prescribed task, meaning that they should be less likely to notice. At least one study suggests that the ability to perform a task does not predict the likelihood of noticing (Simons & Jensen, 2009; for a replication, see Bredemeier & Simons, 2012). In a study I conducted with Melinda Jensen, we measured how well people could track moving objects around a display, gradually increasing the speed until people reached a level of 75% accuracy. Tracking ability varied greatly: Some people could track objects at more than twice the speed others could. Yet, the ability to track objects more easily was unrelated to the odds of noticing an unexpected event. Apparently, as long as people try to perform the tracking task, they are relatively unlikely to notice unexpected events.

What makes these findings interesting and important is that they run counter to our intuitions. Most people are confident they would notice the chest-thumping gorilla. In fact, nearly 90% believe they would spot the gorilla (Levin & Angelone, 2008), and in a national survey, 78% agreed with the statement, "People generally notice when something unexpected enters their field of view, even when they're paying attention to something else" (Simons & Chabris, 2010). Similarly, people are convinced that they would spot errors in movies or changes to a conversation partner (Levin & Angelone, 2008). We think we see and remember far more of our surroundings than we actually do. But why do we have such mistaken intuitions?

One explanation for this mistaken intuition is that our experiences themselves mislead us (Simons & Chabris, 2010). We rarely experience a study situation such as the gorilla experiment in which we are forced to confront something obvious that we just missed. That partly explains why demonstrations such as that one are so powerful: We expect that we would notice the gorilla, and we cannot readily explain away our failure to notice it. Most of the time, we are happily unaware of what we have missed, but we are fully aware of those elements of a scene that we have noticed. Consequently, if we assume our experiences are representative of the state of the world, we will conclude that we notice unexpected events. We don’t easily think about what we’re missing.

Given the limits on attention coupled with our mistaken impression that important events will capture our attention, how has our species survived? Why weren’t our ancestors eaten by unexpected predators? One reason is that our ability to focus attention intently might have been more evolutionarily useful than the ability to notice unexpected events. After all, for an event to be unexpected, it must occur relatively infrequently. Moreover, most events don’t require our immediate attention, so if inattentional blindness delays our ability to notice the events, the consequences could well be minimal. In a social context, others might notice that event and call attention to it. Although inattentional blindness might have had minimal consequences over the course of our evolutionary history, it does have consequences now.

At pedestrian speeds and with minimal distraction, inattentional blindness might not matter for survival. But in modern society, we face greater distractions and move at greater speeds, and even a minor delay in noticing something unexpected can mean the difference between a fender-bender and a lethal collision. If talking on a phone increases your odds of missing a unicycling clown, it likely also increases your odds of missing the child who runs into the street or the car that runs a red light. Why, then, do people continue to talk on the phone when driving? The reason might well be the same mistaken intuition that makes inattentional blindness surprising: Drivers simply do not notice how distracted they are when they are talking on a phone, so they believe they can drive just as well when talking on a phone even though they can’t (Strayer & Johnston, 2001).

So, what can you do about inattentional blindness? The short answer appears to be, “not much.” There is no magical elixir that will overcome the limits on attention, allowing you to notice everything (and that would not be a good outcome anyway). But, there is something you can do to mitigate the consequences of such limits. Now that you know about inattentional blindness, you can take steps to limit its impact by recognizing how your intuitions will lead you astray.

Even though you may think you can drive, text, listen to music, and drink a smoothie at the same time, really, your focus should be only on the road. Everything else is a potential distraction from what's most important: driving safely! [Image: FMHS The Buzz TV, https://goo.gl/TSk2RP, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

First, maximize the attention you do have available by avoiding distractions, especially under conditions for which an unexpected event might be catastrophic. The ring of a new call or the ding of a new text are hard to resist, so make it impossible to succumb to the temptation by turning your phone off or putting it somewhere out of reach when you are driving. If you know that you will be tempted and you know that using your phone will increase inattentional blindness, you must be proactive. Second, pay attention to what others might not notice. If you are a bicyclist, don't assume that the driver sees you, even if they appear to make eye contact. Looking is not the same as seeing. Only by understanding the limits of attention and by recognizing our mistaken beliefs about what we "know" to be true can we avoid the modern-day consequences of those limits.

Outside Resources

Article: Scholarpedia article on inattentional blindness
http://www.scholarpedia.org/article/Inattentional_blindness

Video: The original gorilla video
http://www.youtube.com/watch?v=vJG698U2Mvo

Video: The sequel to the gorilla video
http://www.youtube.com/watch?v=IGQmdoK_ZfY

Web: Website for Chabris & Simons book, The Invisible Gorilla. Includes links to videos and descriptions of the research on inattentional blindness
http://www.theinvisiblegorilla.com

Discussion Questions

1. Many people, upon learning about inattentional blindness, try to think of ways to eliminate it, allowing themselves complete situation awareness. Why might we be far worse off if we were not subject to inattentional blindness?
2. If inattentional blindness cannot be eliminated, what steps might you take to avoid its consequences?
3. Can you think of situations in which inattentional blindness is highly likely to be a problem? Can you think of cases in which inattentional blindness would not have much of an impact?

Vocabulary

Dichotic listening
A task in which different audio streams are presented to each ear. Typically, people are asked to monitor one stream while ignoring the other.

Inattentional blindness
The failure to notice a fully visible, but unexpected, object or event when attention is devoted to something else.

Inattentional deafness
The auditory analog of inattentional blindness. People fail to notice an unexpected sound or voice when attention is devoted to other aspects of a scene.

Selective listening
A method for studying selective attention in which people focus attention on one auditory stream of information while deliberately ignoring other auditory information.

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7

Memory (Encoding, Storage, Retrieval)

Kathleen B. McDermott & Henry L. Roediger

"Memory" is a single term that reflects a number of different abilities: holding information briefly while working with it (working memory), remembering episodes of one's life (episodic memory), and our general knowledge of facts of the world (semantic memory), among other types. Remembering episodes involves three processes: encoding information (learning it, by perceiving it and relating it to past knowledge), storing it (maintaining it over time), and then retrieving it (accessing the information when needed). Failures can occur at any stage, leading to forgetting or to having false memories. The key to improving one's memory is to improve processes of encoding and to use techniques that guarantee effective retrieval. Good encoding techniques include relating new information to what one already knows, forming mental images, and creating associations among information that needs to be remembered. The key to good retrieval is developing effective cues that will lead the rememberer back to the encoded information. Classic mnemonic systems, known since the time of the ancient Greeks and still used by some today, can greatly improve one's memory abilities.

Learning Objectives

- Define and note differences between the following forms of memory: working memory, episodic memory, semantic memory, collective memory.
- Describe the three stages in the process of learning and remembering.
- Describe strategies that can be used to enhance the original learning or encoding of information.
- Describe strategies that can improve the process of retrieval.
- Describe why the classic mnemonic device, the method of loci, works so well.

Introduction

In 2013, Simon Reinhard sat in front of 60 people in a room at Washington University, where he memorized an increasingly long series of digits. On the first round, a computer generated 10 random digits—6 1 9 4 8 5 6 3 7 1—on a screen for 10 seconds. After the series disappeared, Simon typed them into his computer. His recollection was perfect. In the next phase, 20 digits appeared on the screen for 20 seconds. Again, Simon got them all correct. No one in the audience (mostly professors, graduate students, and undergraduate students) could recall the 20 digits perfectly. Then came 30 digits, studied for 30 seconds; once again, Simon didn't misplace even a single digit. For a final trial, 50 digits appeared on the screen for 50 seconds, and again, Simon got them all right. In fact, Simon would have been happy to keep going. His record in this task—called "forward digit span"—is 240 digits!

In some ways memory is like file drawers where you store mental information. Memory is also a series of processes: how does that information get filed to begin with and how does it get retrieved when needed? [Image: M Cruz, https://goo.gl/DhOMgp, CC BY-SA 4.0, https://goo.gl/SWjq94]

When most of us witness a performance like that of Simon Reinhard, we think one of two things: First, maybe he's cheating somehow. (No, he is not.) Second, Simon must have abilities more advanced than the rest of humankind. After all, psychologists established many years ago that the normal memory span for adults is about 7 digits, with some of us able to recall a few more and others a few less (Miller, 1956). That is why the first phone numbers were limited to 7 digits—psychologists determined that many errors occurred (costing the phone company money) when the number was increased to even 8 digits. But in normal testing, no one gets 50 digits correct in a row, much less 240. So, does Simon Reinhard simply have a photographic memory? He does not. Instead, Simon has taught himself simple strategies for remembering that have greatly increased his capacity for remembering virtually any type of material—digits, words, faces and names, poetry, historical dates, and so on. Twelve years earlier, before he started training his memory abilities, he had a digit span of 7, just like most of us. Simon has been training his abilities for about 10 years as of this writing, and has risen to be in the top two of "memory athletes." In 2012, he came in second place in the World Memory Championships (composed of 11 tasks), held in London. He currently ranks second in the world, behind another German competitor, Johannes Mallow. In this module, we reveal what psychologists and others have learned about memory, and we also explain the general principles by which you can improve your own memory for factual material.

Varieties of Memory

For most of us, remembering digits relies on *short-term memory,* or *working memory*—the ability to hold information in our minds for a brief time and work with it (e.g., multiplying 24 x 17 without using paper would rely on working memory). Another type of memory is episodic memory—the ability to remember the episodes of our lives. If you were given the task of recalling everything you did 2 days ago, that would be a test of episodic memory; you would be required to mentally travel through the day in your mind and note the main events. Semantic memory is our storehouse of more-or-less permanent knowledge, such as the meanings of words in a language (e.g., the meaning of "parasol") and the huge collection of facts about the world (e.g., there are 196 countries in the world, and 206 bones in your body). *Collective memory* refers to the kind of memory that people in a group share (whether family, community, schoolmates, or citizens of a state or a country). For example, residents of small towns often strongly identify with those towns, remembering the local customs and historical events in a unique way. That is, the community's collective memory passes stories and recollections between neighbors and to future generations, forming a memory system unto itself.

To be a good chess player you have to learn to increase working memory so you can plan ahead for several offensive moves while simultaneously anticipating - through use of memory - how the other player could counter each of your planned moves. [Image: karpidis, https://goo.gl/EhzMKM, CC BY-SA 2.0, https://goo.gl/jSSrcO]

Psychologists continue to debate the classification of types of memory, as well as which types rely on others (Tulving, 2007), but for this module we will focus on episodic memory. Episodic memory is usually what people think of when they hear the word "memory." For example, when people say that an older relative is “losing her memory” due to Alzheimer’s disease, the type of memory-loss they are referring to is the inability to recall events, or episodic memory. (Semantic memory is actually preserved in early-stage Alzheimer’s disease.) Although remembering specific events that have happened over the course of one’s entire life (e.g., your experiences in sixth grade) can be referred to as **autobiographical memory**, we will focus primarily on the episodic memories of more recent events.

Three Stages of the Learning/Memory Process

Psychologists distinguish between three necessary stages in the learning and memory process: **encoding**, **storage**, and **retrieval** (Melton, 1963). Encoding is defined as the initial learning of information; storage refers to maintaining information over time; retrieval is the ability to access information when you need it. If you meet someone for the first time at a party, you need to encode her name (Lyn Goff) while you associate her name with her face. Then you need to maintain the information over time. If you see her a week later, you need to recognize her face and have it serve as a cue to retrieve her name. Any successful act of remembering requires that all three stages be intact. However, two types of errors can also occur. Forgetting is one type: you see the person you met at the party and you cannot recall her name. The other error is misremembering (false recall or false recognition): you see someone who looks like Lyn Goff and call the person by that name (false recognition of the face). Or, you might see the real Lyn Goff, recognize her face, but then call her by the name of another woman you met at the party (misrecall of her name).

Whenever forgetting or misremembering occurs, we can ask, at which stage in the learning/memory process was there a failure?—though it is often difficult to answer this question with precision. One reason for this inaccuracy is that the three stages are not as discrete as our description implies. Rather, all three stages depend on one another. How we encode information determines how it will be stored and what cues will be effective when we try to retrieve it. And too, the act of retrieval itself also changes the way information is subsequently remembered, usually aiding later recall of the retrieved information. The central point for now is that the three stages—encoding, storage, and retrieval—affect one another, and are inextricably bound together.

Encoding

Encoding refers to the initial experience of perceiving and learning information. Psychologists often study recall by having participants study a list of pictures or words. Encoding in these situations is fairly straightforward. However, “real life” encoding is much more challenging.

When you walk across campus, for example, you encounter countless sights and sounds—friends passing by, people playing Frisbee, music in the air. The physical and mental environments are much too rich for you to encode all the happenings around you or the internal thoughts you have in response to them. So, an important first principle of encoding is that it is selective: we attend to some events in our environment and we ignore others. A second point about encoding is that it is prolific; we are always encoding the events of our lives—attending to the world, trying to understand it. Normally this presents no problem, as our days are filled with routine occurrences, so we don't need to pay attention to everything. But if something does happen that seems strange—during your daily walk across campus, you see a giraffe—then we pay close attention and try to understand why we are seeing what we are seeing.

Right after your typical walk across campus (one without the appearance of a giraffe), you would be able to remember the events reasonably well if you were asked. You could say whom you bumped into, what song was playing from a radio, and so on. However, suppose someone asked you to recall the same walk a month later. You wouldn't stand a chance. You would likely be able to recount the basics of a typical walk across campus, but not the precise details of that particular walk. Yet, if you had seen a giraffe during that walk, the event would have been fixed in your mind for a long time, probably for the rest of your life. You would tell your friends about it, and, on later occasions when you saw a giraffe, you might be reminded of the day you saw one on campus. Psychologists have long pinpointed **distinctiveness**—having an event stand out as quite different from a background of similar events—as a key to remembering events (Hunt, 2003).

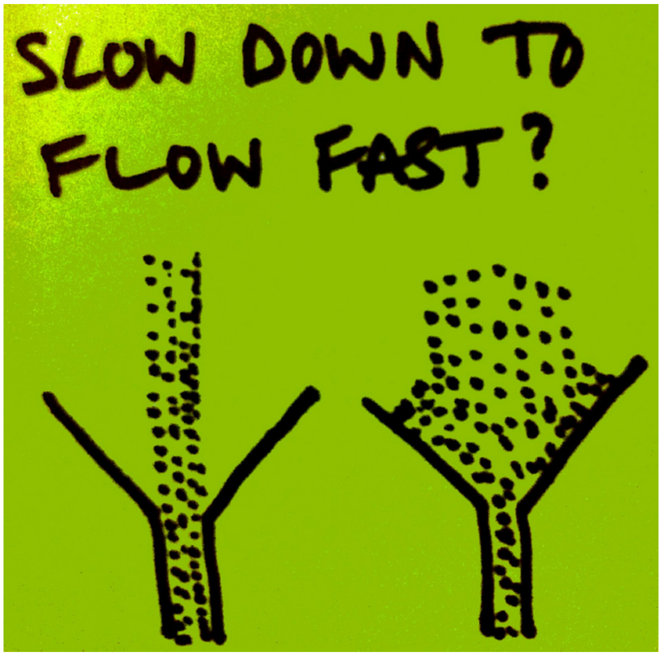
A giraffe in the context of a zoo or its natural habitat may register as nothing more than ordinary, but put it in another setting - in the middle of a campus or a busy city - and its level of distinctiveness increases dramatically. Distinctiveness is a key attribute to remembering events. [Image: Colin J Babb, https://goo.gl/Cci2yl, CC BY-SA 2.0, https://goo.gl/jSSrcO]

In addition, when vivid memories are tinged with strong emotional content, they often seem to leave a permanent mark on us. Public tragedies, such as terrorist attacks, often create vivid memories in those who witnessed them. But even those of us not directly involved in such events may have vivid memories of them, including memories of first hearing about them.

For example, many people are able to recall their exact physical location when they first learned about the assassination or accidental death of a national figure. The term **flashbulb memory** was originally coined by Brown and Kulik (1977) to describe this sort of vivid memory of finding out an important piece of news. The name refers to how some memories seem to be captured in the mind like a flash photograph; because of the distinctiveness and emotionality of the news, they seem to become permanently etched in the mind with exceptional clarity compared to other memories.

Take a moment and think back on your own life. Is there a particular memory that seems sharper than others? A memory where you can recall unusual details, like the colors of mundane things around you, or the exact positions of surrounding objects? Although people have great confidence in flashbulb memories like these, the truth is, our objective accuracy with them is far from perfect (Talarico & Rubin, 2003). That is, even though people may have great confidence in what they recall, their memories are not as accurate (e.g., what the actual colors were; where objects were truly placed) as they tend to imagine. Nonetheless, all other things being equal, distinctive and emotional events are well-remembered.

Details do not leap perfectly from the world into a person's mind. We might say that we went to a party and remember it, but what we remember is (at best) what we encoded. As noted above, the process of encoding is selective, and in complex situations, relatively few of many possible details are noticed and encoded. The process of encoding always involves **recoding**—that is, taking the information from the form it is delivered to us and then converting it in a way that we can make sense of it. For example, you might try to remember the colors of a rainbow by using the acronym ROY G BIV (red, orange, yellow, green, blue, indigo, violet). The process of recoding the colors into a name can help us to remember. However, recoding can also introduce errors—when we accidentally add information during encoding, then remember that *new* material as if it had been part of the actual experience (as discussed below).



Although it requires more effort, using images and associations can improve the process of recoding. [Image: psd, https://goo.gl/9xjcDe, CC BY 2.0, https://goo.gl/9uSnqN]

Psychologists have studied many

recoding strategies that can be used during study to improve retention. First, research advises that, as we study, we should think of the meaning of the events (Craik & Lockhart, 1972), and we should try to relate new events to information we already know. This helps us form associations that we can use to retrieve information later. Second, imagining events also makes them more memorable; creating vivid images out of information (even verbal information) can greatly improve later recall (Bower & Reitman, 1972). Creating imagery is part of the technique Simon Reinhard uses to remember huge numbers of digits, but we can all use images to encode information more effectively. The basic concept behind good encoding strategies is to form distinctive memories (ones that stand out), and to form links or associations among memories to help later retrieval (Hunt & McDaniel, 1993). Using study strategies such as the ones described here is challenging, but the effort is well worth the benefits of enhanced learning and retention.

We emphasized earlier that encoding is selective: people cannot encode all information they are exposed to. However, recoding can add information that was not even seen or heard during the initial encoding phase. Several of the recoding processes, like forming associations between memories, can happen without our awareness. This is one reason people can sometimes remember events that did not actually happen—because during the process of recoding, details got added. One common way of inducing false memories in the laboratory employs a word-list technique (Deese, 1959; Roediger & McDermott, 1995). Participants hear lists of 15 words, like *door, glass, pane, shade, ledge, sill, house, open, curtain, frame, view, breeze, sash, screen,* and *shutter.* Later, participants are given a test in which they are shown a list of words and asked to pick out the ones they'd heard earlier. This second list contains some words from the first list (e.g., *door, pane, frame*) and some words not from the list (e.g., *arm, phone, bottle*). In this example, one of the words on the test is *window*, which—importantly—does not appear in the first list, but which is related to other words in that list. When subjects were tested, they were reasonably accurate with the studied words (*door*, etc.), recognizing them 72% of the time. However, when *window* was on the test, they falsely recognized it as having been on the list 84% of the time (Stadler, Roediger, & McDermott, 1999). The same thing happened with many other lists the authors used. This phenomenon is referred to as the DRM (for Deese-Roediger-McDermott) effect. One explanation for such results is that, while students listened to items in the list, the words triggered the students to think about *window*, even though *window* was never presented. In this way, people seem to encode events that are not actually part of their experience.

Because humans are creative, we are always going beyond the information we are given: we automatically make associations and infer from them what is happening. But, as with the word association mix-up above, sometimes we make false memories from our inferences—remembering the inferences themselves as if they were actual experiences. To illustrate this, Brewer (1977) gave people sentences to remember that were designed to elicit *pragmatic inferences*. Inferences, in general, refer to instances when something is not explicitly stated, but we are still able to guess the undisclosed intention. For example, if your friend told you that she didn't want to go out to eat, you may infer that she doesn't have the money to go out, or that she's too tired. With *pragmatic* inferences, there is usually *one* particular inference you're likely to make. Consider the statement Brewer (1977) gave her participants: "The karate champion hit the cinder block." After hearing or seeing this sentence, participants who were given a memory test tended to remember the statement as having been, "The karate champion *broke* the cinder block." This remembered statement is not necessarily a *logical* inference (i. e., it is perfectly reasonable that a karate champion could hit a cinder block without breaking it). Nevertheless, the *pragmatic* conclusion from hearing such a sentence is that the block was likely broken. The participants remembered this inference they made while hearing the sentence in place of the actual words that were in the sentence (see also McDermott & Chan, 2006).

Encoding—the initial registration of information—is essential in the learning and memory process. Unless an event is encoded in some fashion, it will not be successfully remembered later. However, just because an event is encoded (even if it is encoded well), there's no guarantee that it will be remembered later.

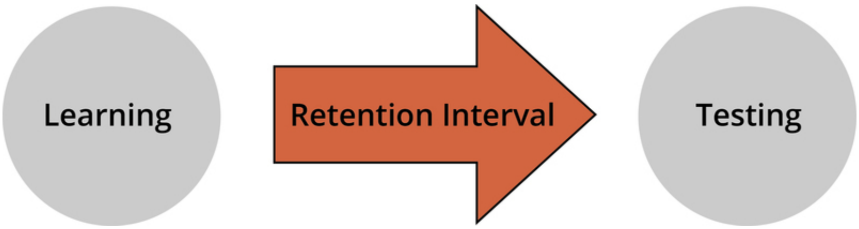
Storage

Every experience we have changes our brains. That may seem like a bold, even strange, claim at first, but it's true. We encode each of our experiences within the structures of the nervous system, making new impressions in the process—and each of those impressions involves changes in the brain. Psychologists (and neurobiologists) say that experiences leave memory traces, or engrams (the two terms are synonyms). Memories have to be stored somewhere in the brain, so in order to do so, the brain biochemically alters itself and its neural tissue. Just like you might write yourself a note to remind you of something, the brain "writes" a memory trace, changing its own

Memory traces, or engrams, are NOT perfectly preserved recordings of past experiences. The traces are combined with current knowledge to reconstruct what we think happened in the past. [Simon Bierdwald, https://goo.gl/JDhdCE, CC BY-NC-SA 2.0, https://goo.gl/jSSrcO] physical composition to do so. The basic idea is that events (occurrences in our environment) create engrams through a process of consolidation: the neural changes that occur after learning to create the memory trace of an experience. Although neurobiologists are concerned with exactly what neural processes change when memories are created, for psychologists, the term *memory trace* simply refers to the physical change in the nervous system (whatever that may be, exactly) that represents our experience.

Although the concept of engram or memory trace is extremely useful, we shouldn't take the term too literally. It is important to understand that memory traces are not perfect little packets of information that lie dormant in the brain, waiting to be called forward to give an accurate report of past experience. Memory traces are not like video or audio recordings, capturing experience with great accuracy; as discussed earlier, we often have errors in our memory, which would not exist if memory traces were perfect packets of information. Thus, it is wrong to think that remembering involves simply "reading out" a faithful record of past experience. Rather, when we remember past events, we reconstruct them with the aid of our memory traces—but also with our current belief of what happened. For example, if you were trying to recall for the police who started a fight at a bar, you may not have a memory trace of who pushed whom first. However, let's say you remember that one of the guys held the door open for you. When thinking back to the start of the fight, this knowledge (of how one guy was friendly to you) may unconsciously influence your memory of what happened in favor of the nice guy. Thus, memory is a construction of what you actually recall and what you believe happened. In a phrase, remembering is reconstructive (we reconstruct our past with the aid of memory traces) not reproductive (a perfect reproduction or recreation of the past).

Psychologists refer to the time between learning and testing as the retention interval. Memories can consolidate during that time, aiding retention. However, experiences can also occur that undermine the memory. For example, think of what you had for lunch yesterday



—a pretty easy task. However, if you had to recall what you had for lunch 17 days ago, you may well fail (assuming you don't eat the same thing every day). The 16 lunches you've had since that one have created **retroactive interference**. Retroactive interference refers to new activities (i.e., the subsequent lunches) during the retention interval (i.e., the time between the lunch 17 days ago and now) that interfere with retrieving the specific, older memory (i.e., the lunch details from 17 days ago). But just as newer things can interfere with remembering older things, so can the opposite happen. *Proactive interference* is when past memories interfere with the encoding of new ones. For example, if you have ever studied a second language, often times the grammar and vocabulary of your native language will pop into your head, impairing your fluency in the foreign language.

Retroactive interference is one of the main causes of forgetting (McGeoch, 1932). In the module *Eyewitness Testimony and Memory Biases* **http://noba.to/uy49tm37** Elizabeth Loftus describes her fascinating work on eyewitness memory, in which she shows how memory for an event can be changed via misinformation supplied during the retention interval. For example, if you witnessed a car crash but subsequently heard people describing it from their own perspective, this new information may interfere with or disrupt your own personal recollection of the crash. In fact, you may even come to remember the event happening exactly as the others described it! This **misinformation effect** in eyewitness memory represents a type of retroactive interference that can occur during the retention interval (see Loftus [2005] for a review). Of course, if correct information is given during the retention interval, the witness's memory will usually be improved.

Although interference may arise between the occurrence of an event and the attempt to recall it, *the effect itself is always expressed when we retrieve memories*, the topic to which we turn next.

Retrieval

Endel Tulving argued that "the key process in memory is retrieval" (1991, p. 91). Why should retrieval be given more prominence than encoding or storage? For one thing, if information were encoded and stored but could not be retrieved, it would be useless. As discussed previously in this module, we encode and store thousands of events—conversations, sights and sounds—every day, creating memory traces. However, we later access only a tiny portion of what we've taken in. Most of our memories will never be used—in the sense of being brought back to mind, consciously. This fact seems so obvious that we rarely reflect on it. All those events that happened to you in the fourth grade that seemed so important then? Now, many years later, you would struggle to remember even a few. You may wonder if the traces of those memories still exist in some latent form. Unfortunately, with currently available methods, it is impossible to know.

Psychologists distinguish information that is available in memory from that which is accessible (Tulving & Pearlstone, 1966). *Available* information is the information that is stored in memory—but precisely how much and what types are stored cannot be known. That is, all we can know is what information we can retrieve—*accessible* information. The assumption is that accessible information represents only a tiny slice of the information available in our brains. Most of us have had the experience of trying to remember some fact or event, giving up, and then—all of a sudden!—it comes to us at a later time, even after we've stopped trying to remember it. Similarly, we all know the experience of failing to recall a fact, but then, if we are given several choices (as in a multiple-choice test), we are easily able to recognize it.

We can't know the entirety of what is in our memory, but only that portion we can actually retrieve. Something that cannot be retrieved now and which is seemingly gone from memory may, with different cues applied, reemerge. [Image: Ores2k, https://goo.gl/1du8Qe, CC BY-NC-SA 2.0, https://goo.gl/jSSrcO]

What factors determine what information can be retrieved from memory? One critical factor is the type of hints, or *cues*, in the environment. You may hear a song on the radio that suddenly evokes memories of an earlier time in your life, even if you were not trying to remember it when the song came on. Nevertheless, the song is closely associated with that time, so it brings the experience to mind.

The general principle that underlies the effectiveness of retrieval cues is the **encoding specificity principle** (Tulving & Thomson, 1973): when people encode information, they do so in specific ways. For example, take the song on the radio: perhaps you heard it while you were at a terrific party, having a great, philosophical conversation with a friend. Thus, the song became part of that whole complex experience. Years later, even though you haven't thought about that party in ages, when you hear the song on the radio, the whole experience rushes back to you. In general, the encoding specificity principle states that, to the extent a retrieval cue (the song) matches or overlaps the memory trace of an experience (the party, the conversation), it will be effective in evoking the memory. A classic experiment on the encoding specificity principle had participants memorize a set of words in a unique setting. Later, the participants were tested on the word sets, either in the same location they learned the words or a different one. As a result of encoding specificity, the students who took the test in the same place they learned the words were actually able to recall more words (Godden & Baddeley, 1975) than the students who took the test in a new setting.

One caution with this principle, though, is that, for the cue to work, it can't match too many other experiences (Nairne, 2002; Watkins, 1975). Consider a lab experiment. Suppose you study 100 items; 99 are words, and one is a picture—of a penguin, item 50 in the list. Afterwards, the cue "recall the picture" would evoke "penguin" perfectly. No one would miss it. However, if the *word* "penguin" were placed in the same spot among the other 99 words, its memorability would be exceptionally worse. This outcome shows the power of distinctiveness that we discussed in the section on encoding: one picture is perfectly recalled from among 99 words because it stands out. Now consider what would happen if the experiment were repeated, but there were 25 pictures distributed within the 100-item list. Although the picture of the penguin would still be there, the probability that the cue "recall the picture" (at item 50) would be useful for the penguin would drop correspondingly. Watkins (1975) referred to this outcome as demonstrating the **cue overload principle**. That is, to be effective, a retrieval cue cannot be overloaded with too many memories. For the cue "recall the picture" to be effective, it should only match one item in the target set (as in the one-picture, 99-word case).

To sum up how memory cues function: for a retrieval cue to be effective, a match must exist between the cue and the desired target memory; furthermore, to produce the best retrieval, the cue-target relationship should be distinctive. Next, we will see how the encoding specificity principle can work in practice.

Psychologists measure memory performance by using production tests (involving recall) or recognition tests (involving the selection of correct from incorrect information, e.g., a multiple-choice test). For example, with our list of 100 words, one group of people might be asked to recall the list in any order (a free recall test), while a different group might be asked to circle the 100 studied words out of a mix with another 100, unstudied words (a recognition test). In this situation, the recognition test would likely produce better performance from participants than the recall test.

We usually think of recognition tests as being quite easy, because the cue for retrieval is a copy of the actual event that was presented for study. After all, what could be a better cue than the exact target (memory) the person is trying to access? In most cases, this line of reasoning is true; nevertheless, recognition tests do not provide perfect indexes of what is stored in memory. That is, you can fail to recognize a target staring you right in the face, yet be able to recall it later with a different set of cues (Watkins & Tulving, 1975). For example, suppose you had the task of recognizing the surnames of famous authors. At first, you might think that being given the actual last name would always be the best cue. However, research has shown this not necessarily to be true (Muter, 1984). When given names such as Tolstoy, Shaw, Shakespeare, and Lee, subjects might well say that Tolstoy and Shakespeare are famous authors, whereas Shaw and Lee are not. But, when given a cued recall test using first names, people often recall items (produce them) that they had failed to recognize before. For example, in this instance, a cue like *George Bernard* _______ often leads to a recall of "Shaw," even though people initially failed to recognize *Shaw* as a famous author's name. Yet, when given the cue "William," people may not come up with Shakespeare, because William is a common name that matches many people (the cue overload principle at work). This strange fact—that recall can sometimes lead to better performance than recognition—can be explained by the encoding specificity principle. As a cue, *George Bernard* _________ matches the way the famous writer is stored in memory better than does his surname, Shaw, does (even though it is the target). Further, the match is quite distinctive with *George Bernard* ___________, but the cue *William* _________________ is much more overloaded (Prince William, William Yeats, William Faulkner, will.i.am).

The phenomenon we have been describing is called the *recognition failure of recallable words*, which highlights the point that a cue will be most effective depending on how the information has been encoded (Tulving & Thomson, 1973). The point is, the cues that work best to evoke retrieval are those that recreate the event or name to be remembered, whereas sometimes even the target itself, such as *Shaw* in the above example, is not the best cue. Which cue will be most effective depends on how the information has been encoded.

Whenever we think about our past, we engage in the act of retrieval. We usually think that retrieval is an objective act because we tend to imagine that retrieving a memory is like pulling a book from a shelf, and after we are done with it, we return the book to the shelf just as it was. However, research shows this assumption to be false; far from being a static repository of data, the memory is constantly changing. In fact, every time we retrieve a memory, it is altered. For example, the act of retrieval itself (of a fact, concept, or event) makes the retrieved memory much more likely to be retrieved again, a phenomenon called the *testing effect* or the *retrieval practice effect* (Pyc & Rawson, 2009; Roediger & Karpicke, 2006). However, retrieving some information can actually cause us to forget other information related to it, a phenomenon called *retrieval-induced forgetting* (Anderson, Bjork, & Bjork, 1994). Thus the act of retrieval can be a double-edged sword—strengthening the memory just retrieved (usually by a large amount) but harming related information (though this effect is often relatively small).

As discussed earlier, retrieval of distant memories is reconstructive. We weave the concrete bits and pieces of events in with assumptions and preferences to form a coherent story (Bartlett, 1932). For example, if during your 10th birthday, your dog got to your cake before you did, you would likely tell that story for years afterward. Say, then, in later years you misremember where the dog actually found the cake, but repeat that error over and over during subsequent retellings of the story. Over time, that inaccuracy would become a basic fact of the event in your mind. Just as retrieval practice (repetition) enhances accurate memories, so will it strengthen errors or false memories (McDermott, 2006). Sometimes memories can even be manufactured just from hearing a vivid story. Consider the following episode, recounted by Jean Piaget, the famous developmental psychologist, from his childhood:

> One of my first memories would date, if it were true, from my second year. I can still see, most clearly, the following scene, in which I believed until I was about 15. I was sitting in my pram . . . when a man tried to kidnap me. I was held in by the strap fastened round me while my nurse bravely tried to stand between me and the thief. She received various scratches, and I can still vaguely see those on her face. . . . When I was about 15, my parents received a letter from my former nurse saying that she had been converted to the Salvation Army. She wanted to confess her past faults, and in particular to return the watch she had been given as a reward on this occasion. She had made up the whole story, faking the scratches. I therefore must have heard, as a child, this story, which my parents believed, and projected it into the past in the form of a visual memory. . . . Many real memories are doubtless of the same order. (Norman & Schacter, 1997, pp. 187–188)

Piaget’s vivid account represents a case of a pure reconstructive memory. He heard the tale told repeatedly, and doubtless told it (and thought about it) himself. The repeated telling cemented the events as though they had really happened, just as we are all open to the possibility of having “many real memories ... of the same order.” The fact that one can remember precise details (the location, the scratches) does not necessarily indicate that the memory is true, a point that has been confirmed in laboratory studies, too (e.g., Norman & Schacter, 1997).

Putting It All Together: Improving Your Memory

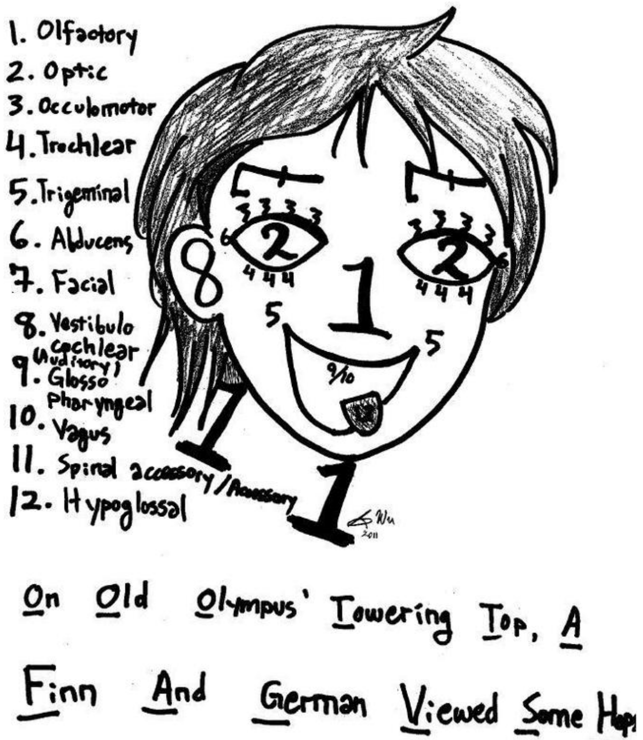
A central theme of this module has been the importance of the encoding and retrieval processes, and their interaction. To recap: to improve learning and memory, we need to encode information in conjunction with excellent cues that will bring back the remembered events when we need them. But how do we do this? Keep in mind the two critical principles we have discussed: to maximize retrieval, we should construct *meaningful* cues that remind us of the original experience, and those cues should be *distinctive* and *not associated with other memories*. These two conditions are critical in maximizing cue effectiveness (Nairne, 2002).

So, how can these principles be adapted for use in many situations? Let's go back to how we started the module, with Simon Reinhard's ability to memorize huge numbers of digits. Although it was not obvious, he applied these same general memory principles, but in a more deliberate way. In fact, all mnemonic devices, or memory aids/tricks, rely on these fundamental principles. In a typical case, the person learns a set of cues and then applies these cues to learn and remember information. Consider the set of 20 items below that are easy to learn and remember (Bower & Reitman, 1972).

1. is a gun. 11 is penny-one, hot dog bun.
2. is a shoe. 12 is penny-two, airplane glue.
3. is a tree. 13 is penny-three, bumble bee.
4. is a door. 14 is penny-four, grocery store.
5. is knives. 15 is penny-five, big beehive.
6. is sticks. 16 is penny-six, magic tricks.
7. is oven. 17 is penny-seven, go to heaven.
8. is plate. 18 is penny-eight, golden gate.
9. is wine. 19 is penny-nine, ball of twine.
10. is hen. 20 is penny-ten, ballpoint pen.

It would probably take you less than 10 minutes to learn this list and practice recalling it several times (remember to use retrieval practice!). If you were to do so, you would have a set of peg words on which you could "hang" memories. In fact, this mnemonic device is called the *peg word technique*. If you then needed to remember some discrete items—say a grocery list, or points you wanted to make in a speech—this method would let you do so in a very precise yet flexible way. Suppose you had to remember bread, peanut butter, bananas, lettuce, and so on. The way to use the method is to form a vivid image of what you want to remember and imagine it interacting with your peg words (as many as you need). For example, for these items, you might imagine a large gun (the first peg word) shooting a loaf of bread, then a jar of peanut butter inside a shoe, then large bunches of bananas hanging from a tree, then a door slamming on a head of lettuce with leaves flying everywhere. The idea is to provide good, distinctive cues (the weirder the better!) for the information you need to remember while you are learning it. If you do this, then retrieving it later is relatively easy. You know your cues perfectly (one is gun, etc.), so you simply go through your cue word list and "look" in your mind's eye at the image stored there (bread, in this case).

This peg word method may sound strange at first, but it works quite well, even with little



Example of a mneumonic system created by a student to study cranial nerves. [Image: Kelidimari, https://goo.gl/kiA1kP, CC BY-SA 3.0, https://goo.gl/SCkRfm]

training (Roediger, 1980). One word of warning, though, is that the items to be remembered need to be presented relatively slowly at first, until you have practice associating each with its cue word. People get faster with time. Another interesting aspect of this technique is that it’s just as easy to recall the items in backwards order as forwards. This is because the peg words provide direct access to the memorized items, regardless of order.

How did Simon Reinhard remember those digits? Essentially he has a much more complex system based on these same principles. In his case, he uses “memory palaces” (elaborate scenes with discrete places) combined with huge sets of images for digits. For example, imagine mentally walking through the home where you grew up and identifying as many distinct areas and objects as possible. Simon has hundreds of such memory palaces that he uses. Next, for remembering digits, he has memorized a set of 10,000 images. Every four-digit number for him immediately brings forth a mental image. So, for example, 6187 might recall Michael Jackson. When Simon hears all the numbers coming at him, he places an image for every four digits into locations in his memory palace. He can do this at an incredibly rapid rate, faster than 4 digits per 4 seconds when they are flashed visually, as in the demonstration at the beginning of the module. As noted, his record is 240 digits, recalled in exact order. Simon also holds the world record in an event called “speed cards,” which involves memorizing the precise order of a shuffled deck of cards. Simon was able to do this in 21.19 seconds! Again, he uses his memory palaces, and he encodes groups of cards as single images.

Many books exist on how to improve memory using mnemonic devices, but all involve forming distinctive encoding operations and then having an infallible set of memory cues. We should add that to develop and use these memory systems beyond the basic peg system outlined above takes a great amount of time and concentration. The World Memory Championships are held every year and the records keep improving. However, for most common purposes, just keep in mind that to remember well you need to encode information in a distinctive way and to have good cues for retrieval. You can adapt a system that will meet most any purpose.

Outside Resources

Book: Brown, P.C., Roediger, H. L. & McDaniel, M. A. (2014). Make it stick: The science of successful learning. Cambridge, MA: Harvard University Press.
https://www.amazon.com/Make-Stick-Science-Successful-Learning/dp/0674729013

Student Video 1: Eureka Foong\\\\\\\'s - The Misinformation Effect. This is a student-made video illustrating this phenomenon of altered memory. It was one of the winning entries in the 2014 Noba Student Video Award.
https://www.youtube.com/watch?v=iMPIWkFtd88

Student Video 2: Kara McCord\\\\\\\'s - Flashbulb Memories. This is a student-made video illustrating this phenomenon of autobiographical memory. It was one of the winning entries in the 2014 Noba Student Video Award.
https://www.youtube.com/watch?v=mPhW9bUI4F0

Student Video 3: Ang Rui Xia & Ong Jun Hao\\\\\\\'s - The Misinformation Effect. Another student-made video exploring the misinformation effect. Also an award winner from 2014.
https://www.youtube.com/watch?v=gsn9iKmOJLQ

Video: Simon Reinhard breaking the world record in speedcards.
http://vimeo.com/12516465

Web: Retrieval Practice, a website with research, resources, and tips for both educators and learners around the memory-strengthening skill of retrieval practice.
http://www.retrievalpractice.org/

Discussion Questions

1. Mnemonists like Simon Reinhard develop mental “journeys,” which enable them to use the method of loci. Develop your own journey, which contains 20 places, in order, that you know well. One example might be: the front walkway to your parents’ apartment; their doorbell; the couch in their living room; etc. Be sure to use a set of places that you know well and that have a natural order to them (e.g., the walkway comes before the doorbell). Now you are more than halfway toward being able to memorize a set of 20 nouns, in order, rather quickly. As an optional second step, have a friend make a list of 20 such nouns and read them to you, slowly (e.g., one every 5 seconds). Use the method to attempt to

remember the 20 items.

2. Recall a recent argument or misunderstanding you have had about memory (e.g., a debate over whether your girlfriend/boyfriend had agreed to something). In light of what you have just learned about memory, how do you think about it? Is it possible that the disagreement can be understood by one of you making a pragmatic inference?
3. Think about what you've learned in this module and about how you study for tests. On the basis of what you have learned, is there something you want to try that might help your study habits?

Vocabulary

Autobiographical memory
Memory for the events of one's life.

Consolidation
The process occurring after encoding that is believed to stabilize memory traces.

Cue overload principle
The principle stating that the more memories that are associated to a particular retrieval cue, the less effective the cue will be in prompting retrieval of any one memory.

Distinctiveness
The principle that unusual events (in a context of similar events) will be recalled and recognized better than uniform (nondistinctive) events.

Encoding
The initial experience of perceiving and learning events.

Encoding specificity principle
The hypothesis that a retrieval cue will be effective to the extent that information encoded from the cue overlaps or matches information in the engram or memory trace.

Engrams
A term indicating the change in the nervous system representing an event; also, memory trace.

Episodic memory
Memory for events in a particular time and place.

Flashbulb memory
Vivid personal memories of receiving the news of some momentous (and usually emotional) event.

Memory traces
A term indicating the change in the nervous system representing an event.

Misinformation effect
When erroneous information occurring after an event is remembered as having been part of

the original event.

Mnemonic devices
A strategy for remembering large amounts of information, usually involving imaging events occurring on a journey or with some other set of memorized cues.

Recoding
The ubiquitous process during learning of taking information in one form and converting it to another form, usually one more easily remembered.

Retrieval
The process of accessing stored information.

Retroactive interference
The phenomenon whereby events that occur after some particular event of interest will usually cause forgetting of the original event.

Semantic memory
The more or less permanent store of knowledge that people have.

Storage
The stage in the learning/memory process that bridges encoding and retrieval; the persistence of memory over time.

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8

Factors Influencing Learning

Aaron Benjamin

Learning is a complex process that defies easy definition and description. This module reviews some of the philosophical issues involved with defining learning and describes in some detail the characteristics of learners and of encoding activities that seem to affect how well people can acquire new memories, knowledge, or skills. At the end, we consider a few basic principles that guide whether a particular attempt at learning will be successful or not.

Learning Objectives

- Consider what kinds of activities constitute learning.
- Name multiple forms of learning.
- List some individual differences that affect learning.
- Describe the effect of various encoding activities on learning.
- Describe three general principles of learning.

Introduction

What do you do when studying for an exam? Do you read your class notes and textbook (hopefully not for the very first time)? Do you try to find a quiet place without distraction? Do you use flash cards to test your knowledge? The choices you make reveal your theory of learning, but there is no reason for you to limit yourself to your own intuitions. There is a vast and vibrant science of learning, in which researchers from psychology, education, and neuroscience study basic principles of learning and memory.

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When you study for a test, you incorporate your past knowledge into learning this new knowledge. That is, depending on your previous experiences, you will "learn" the material in different ways. [Image: UBC Learning Commons, https://goo.gl/eT0jvd, CC BY 2.0, https://goo.gl/BRvSA7]

In fact, learning is a much broader domain than you might think. Consider: Is listening to music a form of learning? More often, it seems listening to music is a way of avoiding learning. But we know that your brain's response to auditory information changes with your experience with that information, a form of learning called auditory perceptual learning (Polley, Steinberg, & Merzenich, 2006). Each time we listen to a song, we hear it differently because of our experience. When we exhibit changes in behavior without having intended to learn something, that is called implicit learning (Seger, 1994), and when we exhibit changes in our behavior that reveal the influence of past experience even though we are not attempting to use that experience, that is called implicit memory (Richardson-Klavehn & Bjork, 1988).

Other well-studied forms of learning include the types of learning that are general across species. We can't ask a slug to learn a poem or a lemur to learn to bat left-handed, but we can assess learning in other ways. For example, we can look for a change in our responses to things when we are repeatedly stimulated. If you live in a house with a grandfather clock, you know that what was once an annoying and intrusive sound is now probably barely audible to you. Similarly, poking an earthworm again and again is likely to lead to a reduction in its retraction from your touch. These phenomena are forms of nonassociative learning, in which single repeated exposure leads to a change in behavior (Pinsker, Kupfermann, Castelluci, & Kandel, 1970). When our response lessens with exposure, it is called habituation, and when it increases (like it might with a particularly annoying laugh), it is called sensitization. Animals can also learn about relationships between things, such as when an alley cat learns that the sound of janitors working in a restaurant precedes the dumping of delicious new garbage (an example of stimulus-stimulus learning called classical conditioning), or when a dog learns to roll over to get a treat (a form of stimulus-response learning called operant conditioning). These forms of learning will be covered in the module on Conditioning and Learning (http://noba.to/ajxhcqdr).

Here, we'll review some of the conditions that affect learning, with an eye toward the type of explicit learning we do when trying to learn something. Jenkins (1979) classified experiments on learning and memory into four groups of factors (renamed here): learners, encoding activities, materials, and retrieval. In this module, we'll focus on the first two categories; the module on Memory (http://noba.to/bdc4uger) will consider other factors more generally.

Learners

People bring numerous individual differences with them into memory experiments, and many of these variables affect learning. In the classroom, motivation matters (Pintrich, 2003), though experimental attempts to induce motivation with money yield only modest benefits (Heyer & O'Kelly, 1949). Learners are, however, quite able to allocate more effort to learning prioritized over unimportant materials (Castel, Benjamin, Craik, & Watkins, 2002).

In addition, the organization and planning skills that a learner exhibits matter a lot (Garavalia & Gredler, 2002), suggesting that the efficiency with which one organizes self-guided learning is an important component of learning. We will return to this topic soon.

One well-studied and important variable is working memory capacity. Working memory describes the form of memory we use to hold onto information temporarily. Working memory is used, for example, to keep track of where we are in the course of a complicated math problem, and what the relevant outcomes of prior steps in that problem are. Higher scores on working memory measures are predictive of better reasoning skills (Kyllonen & Christal, 1990), reading comprehension (Daneman & Carpenter, 1980), and even better control of attention (Kane, Conway, Hambrick, & Engle, 2008).

Research attests that we can hold between 5 and 9 individual pieces of information in our working memory at once. This is partly why in the 1950s Bell Labs developed a 7-digit phone number system. [Image: Diamondmagna, https://goo.gl/xeUxfw, CC BY-SA 3.0, https://goo.gl/eLCn2O]

Anxiety also affects the quality of learning. For example, people with math anxiety have a smaller capacity for remembering math-related information in working memory, such as the results of carrying a digit in arithmetic (Ashcraft & Kirk, 2001). Having students write about their specific anxiety seems to reduce the worry associated with tests and increases performance on math tests (Ramirez & Beilock, 2011).

One good place to end this discussion is to consider the role of expertise. Though there probably is a finite capacity on our ability to store information (Landauer, 1986), in practice, this concept is misleading. In fact, because the usual bottleneck to remembering something is our ability to *access* information, not our space to *store* it, having more knowledge or expertise actually enhances our ability to learn new information. A classic example can be seen in comparing a chess master with a chess novice on their ability to learn and remember the positions of pieces on a chessboard (Chase & Simon, 1973). In that experiment, the master remembered the location of many more pieces than the novice, even after only a very short glance. Maybe chess masters are just smarter than the average chess beginner, and have better memory? No: The advantage the expert exhibited only was apparent when the pieces were arranged in a plausible format for an ongoing chess game; when the pieces were placed randomly, both groups did equivalently poorly. Expertise allowed the master to **chunk** (Simon, 1974) multiple pieces into a smaller number of pieces of information—but only when that information was structured in such a way so as to allow the application of that expertise.

Encoding Activities

What we do when we're learning is very important. We've all had the experience of reading something and suddenly coming to the realization that we don't remember a single thing, even the sentence that we just read. *How* we go about **encoding** information determines a lot about how much we remember.

You might think that the most important thing is to *try* to learn. Interestingly, this is not true, at least not completely. Trying to learn a list of words, as compared to just evaluating each word for its part of speech (i.e., noun, verb, adjective) does help you *recall* the words—that is, it helps you remember and write down more of the words later. But it actually impairs your ability to *recognize* the words—to judge on a later list which words are the ones that you studied (Eagle & Leiter, 1964). So this is a case in which **incidental learning**—that is, learning without the intention to learn—is better than **intentional learning**.

Such examples are not particularly rare and are not limited to recognition. Nairne, Pandeirada, and Thompson (2008) showed, for example, that survival processing—thinking about and rating each word in a list for its relevance in a survival scenario—led to much higher recall than intentional learning (and also higher, in fact, than other encoding activities that are also known to lead to high levels of recall). Clearly, merely intending to learn something is not enough. *How* a learner actively processes the material plays a large role; for example, reading words and evaluating their meaning leads to better learning than reading them and evaluating the way that the words look or sound (Craik & Lockhart, 1972). These results suggest that individual differences in motivation will not have a large effect on learning unless learners also have accurate ideas about how to effectively learn material when they care to do so.

Motivation to learn doesn't make much of a difference unless learners use effective strategies for encoding the information they want to retain. Although they're not flashy, methods like spaced practice, interleaving, and frequent testing are among the most effective ways to apply your efforts. [Image: Cali4beach, https://goo.gl/twjIVg, CC BY 2.0, https://goo.gl/BRvSA7]

So, do learners know how to effectively encode material? People allowed to freely allocate their time to study a list of words do remember those words better than a group that doesn't have control over their own study time, though the advantage is relatively small and is limited to the subset of learners who choose to spend more time on the more difficult material (Tullis & Benjamin, 2011). In addition, learners who have an opportunity to review materials that they select for restudy often learn more than another group that is asked to restudy the materials that they *didn't* select for restudy (Kornell & Metcalfe, 2006). However, this advantage also appears to be relatively modest (Kimball, Smith, & Muntean, 2012) and wasn't apparent in a group of older learners (Tullis & Benjamin, 2012). Taken together, all of the evidence seems to support the claim that self-control of learning can be effective, but only when learners have good ideas about what an effective learning strategy is.

One factor that appears to have a big effect and that learners do not always appear to understand is the effect of scheduling repetitions of study. If you are studying for a final exam next week and plan to spend a total of five hours, what is the best way to distribute your study? The evidence is clear that *spacing* one's repetitions apart in time is superior than *massing* them all together (Baddeley & Longman, 1978; Bahrick, Bahrick, Bahrick, & Bahrick, 1993; Melton, 1967). Increasing the spacing between consecutive presentations appears to benefit learning yet further (Landauer & Bjork, 1978).

A similar advantage is evident for the practice of interleaving multiple skills to be learned: For example, baseball batters improved more when they faced a mix of different types of pitches than when they faced the same pitches blocked by type (Hall, Domingues, & Cavazos, 1994).

Students also showed better performance on a test when different types of mathematics problems were interleaved rather than blocked during learning (Taylor & Rohrer, 2010).

One final factor that merits discussion is the role of testing. Educators and students often think about testing as a way of assessing knowledge, and this is indeed an important use of tests. But tests themselves affect memory, because retrieval is one of the most powerful ways of enhancing learning (Roediger & Butler, 2013). Self-testing is an underutilized and potent means of making learning more durable.

General Principles of Learning

We've only begun to scratch the surface here of the many variables that affect the quality and content of learning (Mullin, Herrmann, & Searleman, 1993). But even within this brief examination of the differences between people and the activities they engage in can we see some basic principles of the learning process.

The value of effective metacognition

To be able to guide our own learning effectively, we must be able to evaluate the progress of our learning accurately and choose activities that enhance learning efficiently. It is of little use to study for a long time if a student cannot discern between what material she has or has not mastered, and if additional study activities move her no closer to mastery. Metacognition describes the knowledge and skills people have in monitoring and controlling their own learning and memory. We can work to acquire better metacognition by paying attention to our successes and failures in estimating what we do and don't know, and by using testing often to monitor our progress.

Transfer-appropriate processing

Sometimes, it doesn't make sense to talk about whether a particular encoding activity is good or bad for learning. Rather, we can talk about whether that activity is good for learning *as revealed by a particular test*. For example, although reading words for meaning leads to better performance on a test of recall or recognition than paying attention to the pronunciation of the word, it leads to *worse* performance on a test that taps knowledge of that pronunciation, such as whether a previously studied word rhymes with another word (Morris, Bransford, & Franks, 1977). The principle of transfer-appropriate processing states that memory is "better" when the test taps the same type of knowledge as the original encoding activity. When thinking about how to learn material, we should always be thinking about the situations in which we are likely to need access to that material. An emergency responder who needs access to learned procedures under conditions of great stress should learn differently from a hobbyist learning to use a new digital camera.

The value of forgetting

In order to not forget things, we employ a variety of tricks (like scribbling a quick note on your hand). However, if we were unable to forget information, it would interfere with learning new or contradictory material. [Image: Andrea Maria Cannata, https://goo.gl/ylTbGG, CC BY-NC 2.0, https://goo.gl/qOP7mj]

Forgetting is sometimes seen as the enemy of learning, but, in fact, forgetting is a highly desirable part of the learning process. The main bottleneck we face in using our knowledge is being able to access it. We have all had the experience of retrieval failure—that is, not being able to remember a piece of information that we know we have, and that we can access easily once the right set of cues is provided. Because access is difficult, it is important to jettison information that is not needed—that is, to forget it. Without forgetting, our minds would become cluttered with out-of-date or irrelevant information. And, just imagine how complicated life would be if we were unable to forget the names of past acquaintances, teachers, or romantic partners.

But the value of forgetting is even greater than that. There is lots of evidence that *some* forgetting is a prerequisite for *more* learning. For example, the previously discussed benefits of distributing practice opportunities may arise in part because of the greater forgetting that takes places between those spaced learning events. It is for this reason that some encoding activities that are difficult and lead to the appearance of slow learning actually lead to superior learning in the long run (Bjork, 2011). When we opt for learning activities that enhance learning quickly, we must be aware that these are not always the same techniques that lead to durable, long-term learning.

Conclusion

To wrap things up, let’s think back to the questions we began the module with. What might you now do differently when preparing for an exam? Hopefully, you will think about testing yourself frequently, developing an accurate sense of what you do and do not know, how you are likely to use the knowledge, and using the scheduling of tasks to your advantage. If you are learning a new skill or new material, using the scientific study of learning as a basis for the study and practice decisions you make is a good bet.

Outside Resources

Video: The First 20 hours – How to Learn Anything - Watch a video by Josh Kaufman about how we can get really good at almost anything with 20 hours of efficient practice.
https://www.youtube.com/watch?v=5MgBikgcWnY

Video: The Learning Scientists - Terrific YouTube Channel with videos covering such important topics as interleaving, spaced repetition, and retrieval practice.
https://www.youtube.com/channel/UCjbAmxL6GZXiaoXuNE7cIYg

Video: What we learn before we're born - In this video, science writer Annie Murphy Paul answers the question "When does learning begin?" She covers through new research that shows how much we learn in the womb — from the lilt of our native language to our soon-to-be-favorite foods.
https://www.ted.com/talks/annie_murphy_paul_what_we_learn_before_we_re_born

Web: Neuroscience News - This is a science website dedicated to neuroscience research, with this page addressing fascinating new memory research.
http://neurosciencenews.com/neuroscience-terms/memory-research/

Web: The Learning Scientists - A websitecreated by three psychologists who wanted to make scientific research on learning more accessible to students, teachers, and other educators.
http://www.learningscientists.org/

Discussion Questions

1. How would you best design a computer program to help someone learn a new foreign language? Think about some of the principles of learning outlined in this module and how those principles could be instantiated in "rules" in a computer program.
2. Would you rather have a really good memory or really good metacognition? How might you train someone to develop better metacognition if he or she doesn't have a very good memory, and what would be the consequences of that training?
3. In what kinds of situations not discussed here might you find a benefit of forgetting on learning?

Vocabulary

Chunk
The process of grouping information together using our knowledge.

Classical conditioning
Describes stimulus-stimulus associative learning.

Encoding
The pact of putting information into memory.

Habituation
Occurs when the response to a stimulus decreases with exposure.

Implicit learning
Occurs when we acquire information without intent that we cannot easily express.

Implicit memory
A type of long-term memory that does not require conscious thought to encode. It's the type of memory one makes without intent.

Incidental learning
Any type of learning that happens without the intention to learn.

Intentional learning
Any type of learning that happens when motivated by intention.

Metacognition
Describes the knowledge and skills people have in monitoring and controlling their own learning and memory.

Nonassociative learning
Occurs when a single repeated exposure leads to a change in behavior.

Operant conditioning
Describes stimulus-response associative learning.

Perceptual learning

Occurs when aspects of our perception changes as a function of experience.

Sensitization
Occurs when the response to a stimulus increases with exposure

Transfer-appropriate processing
A principle that states that memory performance is superior when a test taps the same cognitive processes as the original encoding activity.

Working memory
The form of memory we use to hold onto information temporarily, usually for the purposes of manipulation.

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9

Forgetting and Amnesia

Nicole Dudukovic & Brice Kuhl

This module explores the causes of everyday forgetting and considers pathological forgetting in the context of amnesia. Forgetting is viewed as an adaptive process that allows us to be efficient in terms of the information we retain.

Learning Objectives

- Identify five reasons we forget and give examples of each.
- Describe how forgetting can be viewed as an adaptive process.
- Explain the difference between anterograde and retrograde amnesia.

Introduction

Chances are that you have experienced memory lapses and been frustrated by them. You may have had trouble remembering the definition of a key term on an exam or found yourself unable to recall the name of an actor from one of your favorite TV shows. Maybe you forgot to call your aunt on her birthday or you routinely forget where you put your cell phone. Oftentimes, the bit of information we are searching for comes back to us, but sometimes it does not. Clearly, forgetting seems to be a natural part of life. Why do we forget? And is forgetting always a bad thing?

Causes of Forgetting

Forgetting can often be obnoxious or even embarrassing. But as we explore this module, you'll learn that forgetting is important and necessary for everyday functionality. [Image: jazbeck, https://goo.gl/nkRrJy, CC BY 2.0, https://goo.gl/BRvSA7]

One very common and obvious reason why you cannot remember a piece of information is because you did not learn it in the first place. If you fail to encode information into memory, you are not going to remember it later on. Usually, **encoding** failures occur because we are distracted or are not paying attention to specific details. For example, people have a lot of trouble recognizing an actual penny out of a set of drawings of very similar pennies, or lures, even though most of us have had a lifetime of experience handling pennies (Nickerson & Adams, 1979). However, few of us have studied the features of a penny in great detail, and since we have not attended to those details, we fail to recognize them later. Similarly, it has been well documented that distraction during learning impairs later memory (e.g., Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). Most of the time this is not problematic, but in certain situations, such as when you are studying for an exam, failures to encode due to distraction can have serious repercussions.

Another proposed reason why we forget is that memories fade, or **decay**, over time. It has been known since the pioneering work of Hermann Ebbinghaus (1885/1913) that as time passes, memories get harder to recall. Ebbinghaus created more than 2,000 nonsense syllables, such as *dax*, *bap*, and *rif*, and studied his own memory for them, learning as many as 420 lists of 16 nonsense syllables for one experiment. He found that his memories diminished as time passed, with the most forgetting happening early on after learning. His observations and subsequent research suggested that if we do not rehearse a memory and the neural representation of that memory is not reactivated over a long period of time, the memory representation may disappear entirely or fade to the point where it can no longer be accessed. As you might imagine, it is hard to definitively prove that a memory has decayed as opposed to it being inaccessible for another reason. Critics argued that forgetting must be due to processes other than simply the passage of time, since disuse of a memory does not always guarantee forgetting (McGeoch, 1932). More recently, some memory theorists have proposed that recent memory traces may be degraded or disrupted by new experiences (Wixted, 2004). Memory traces need to be **consolidated**, or transferred from the hippocampus to more durable representations in the cortex, in order for them to last (McGaugh, 2000). When the consolidation process is interrupted by the encoding of other experiences, the memory trace for the original experience does not get fully developed and thus is forgotten.

At times, we will completely blank on something we're certain we've learned - people we went to school with years ago for example. However, once we get the right retrieval cue (a name perhaps), the memory (faces or experiences) rushes back to us like it was there all along. [Image: sbhsclass84, https://goo.gl/sHZyQI, CC BY-SA 2.0, https://goo.gl/rxiUsF]

Both encoding failures and decay account for more permanent forms of forgetting, in which the memory trace does not exist, but forgetting may also occur when a memory exists yet we temporarily cannot access it. This type of forgetting may occur when we lack the appropriate **retrieval** cues for bringing the memory to mind. You have probably had the frustrating experience of forgetting your password for an online site. Usually, the password has not been permanently forgotten; instead, you just need the right reminder to remember what it is. For example, if your password was "pizza0525," and you received the password hints "favorite food" and "Mom's birthday," you would easily be able to retrieve it. Retrieval hints can bring back to mind seemingly forgotten memories (Tulving & Pearlstone, 1966). One real-life illustration of the importance of retrieval cues comes from a study showing that whereas people have difficulty recalling the names of high school classmates years after graduation, they are easily able to recognize the names and match them to the appropriate faces (Bahrick, Bahrick, & Wittinger, 1975). The names are powerful enough retrieval cues that they bring back the memories of the faces that went with them. The fact that the presence of the right retrieval cues is critical for remembering adds to the difficulty in proving that a memory is permanently forgotten as opposed to temporarily unavailable.

Retrieval failures can also occur because other memories are blocking or getting in the way of recalling the desired memory. This blocking is referred to as interference. For example, you may fail to remember the name of a town you visited with your family on summer vacation because the names of other towns you visited on that trip or on other trips come to mind instead. Those memories then prevent the desired memory from being retrieved. Interference is also relevant to the example of forgetting a password: passwords that we have used for other websites may come to mind and interfere with our ability to retrieve the desired password. Interference can be either proactive, in which old memories block the learning of new related memories, or retroactive, in which new memories block the retrieval of old related memories. For both types of interference, competition between memories seems to be key (Mensink & Raaijmakers, 1988). Your memory for a town you visited on vacation is unlikely to interfere with your ability to remember an Internet password, but it is likely to interfere with your ability to remember a different town's name. Competition between memories can also lead to forgetting in a different way. Recalling a desired memory in the face of competition may result in the inhibition of related, competing memories (Levy & Anderson, 2002). You may have difficulty recalling the name of Kennebunkport, Maine, because other Maine towns, such as Bar Harbor, Winterport, and Camden, come to mind instead. However, if you are able to recall Kennebunkport despite strong competition from the other towns, this may actually change the competitive landscape, weakening memory for those other towns' names, leading to forgetting of them instead.

Box 1. Five Impediments to Remembering

1. Encoding failures - we don't learn the information in the first place
2. Decay - memories fade over time
3. Inadequate retrieval cues - we lack sufficient reminders
4. Interference - other memories get in the way
5. Trying not to remember - we deliberately attempt to keep things out of mind

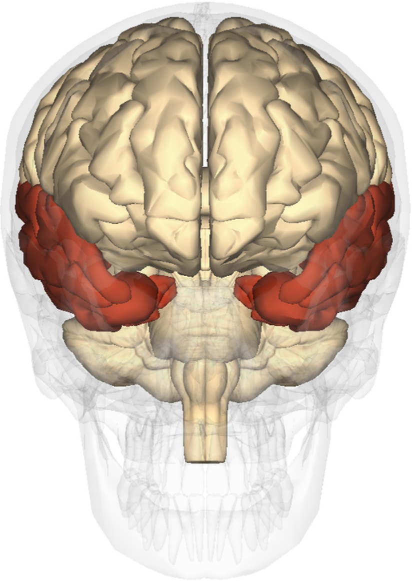
Finally, some memories may be forgotten because *we deliberately attempt to keep them out of mind*. Over time, by actively trying not to remember an event, we can sometimes successfully keep the undesirable memory from being retrieved either by inhibiting the undesirable memory or generating diversionary thoughts (Anderson & Green, 2001). Imagine that you slipped and fell in your high school cafeteria during lunch time, and everyone at the surrounding tables laughed at you. You would likely wish to avoid thinking about that event and might try to prevent it from coming to mind. One way that you could accomplish this is by thinking of other, more positive, events that are associated with the cafeteria. Eventually, this memory may be suppressed to the point that it would only be retrieved with great difficulty (Hertel & Calcaterra, 2005).

Adaptive Forgetting

Could you imagine being unable to forget every path you have taken while hiking? Each new trip, you would be walking around the forest for days, incapable of distinguishing today's path from the prior ones. [Image: Dan Trew, https://goo.gl/8fJWWE, CC BY-SA 2.0, https://goo.gl/rxiUsF]

We have explored five different causes of forgetting. Together they can account for the day-to-day episodes of forgetting that each of us experience. Typically, we think of these episodes in a negative light and view forgetting as a memory failure. Is forgetting ever good? Most people would reason that forgetting that occurs in response to a deliberate attempt to keep an event out of mind is a good thing. No one wants to be constantly reminded of falling on their face in front of all of their friends. However, beyond that, it can be argued that forgetting is adaptive, allowing us to be efficient and hold onto only the most relevant memories (Bjork, 1989; Anderson & Milson, 1989). Shereshevsky, or "S," the mnemonist studied by Alexander Luria (1968), was a man who almost never forgot. His memory appeared to be virtually limitless. He could memorize a table of 50 numbers in under 3 minutes and recall the numbers in rows, columns, or diagonals with ease. He could recall lists of words and passages that he had memorized over a decade before. Yet Shereshevsky found it difficult to function in his everyday life because he was constantly distracted by a flood of details and associations that sprung to mind. His case history suggests that remembering everything is not always a good thing. You may occasionally have trouble remembering where you parked your car, but imagine if every time you had to find your car, every single former parking space came to mind. The task would become impossibly difficult to sort through all of those irrelevant memories. Thus, forgetting is adaptive in that it makes us more efficient. The price of that efficiency is those moments when our memories seem to fail us (Schacter, 1999).

Amnesia



Patients with damage to the temporal lobes may experience anterograde amnesia and/or retrograde amnesia. [Image: en: Anatomography, https://goo.gl/ALPAu6, CC BY-SA 2.1 JP, https://goo.gl/BDF2Z4]

Clearly, remembering everything would be maladaptive, but what would it be like to remember nothing? We will now consider a profound form of forgetting called amnesia that is distinct from more ordinary forms of forgetting. Most of us have had exposure to the concept of amnesia through popular movies and television. Typically, in these fictionalized portrayals of amnesia, a character suffers some type of blow to the head and suddenly has no idea who they are and can no longer recognize their family or remember any events from their past. After some period of time (or another blow to the head), their memories come flooding back to them. Unfortunately, this portrayal of amnesia is not very accurate. What does amnesia typically look like?

The most widely studied amnesic patient was known by his initials H. M. (Scoville & Milner, 1957). As a teenager, H. M. suffered from severe epilepsy, and in 1953, he underwent surgery to have both of his medial temporal lobes removed to relieve his epileptic seizures. The **medial temporal lobes** encompass the hippocampus and surrounding cortical tissue. Although the surgery was successful in reducing H. M.'s seizures and his general intelligence was preserved, the surgery left H. M. with a profound and permanent memory deficit. From the time of his surgery until his death in 2008, H. M. was unable to learn new information, a memory impairment called **anterograde amnesia**. H. M. could not remember any event that occurred since his surgery, including highly significant ones, such as the death of his father. He could not remember a conversation he had a few minutes prior or recognize the face of someone who had visited him that same day. He could keep information in his short-term, or working, memory, but when his attention turned to something else, that information was lost for good. It is important to note that H. M.'s memory impairment was restricted to **declarative memory**, or conscious memory for facts and events. H. M. could learn new motor skills and showed improvement on motor tasks even in the absence of any memory for having performed the task before (Corkin, 2002).

In addition to anterograde amnesia, H. M. also suffered from **temporally graded retrograde amnesia**. **Retrograde amnesia** refers to an inability to retrieve old memories that occurred before the onset of amnesia. Extensive retrograde amnesia in the absence of anterograde amnesia is very rare (Kopelman, 2000). More commonly, retrograde amnesia co-occurs with anterograde amnesia and shows a temporal gradient, in which memories closest in time to the onset of amnesia are lost, but more remote memories are retained (Hodges, 1994). In the case of H. M., he could remember events from his childhood, but he could not remember events that occurred a few years before the surgery.

Amnesiac patients with damage to the hippocampus and surrounding medial temporal lobes typically manifest a similar clinical profile as H. M. The degree of anterograde amnesia and retrograde amnesia depend on the extent of the medial temporal lobe damage, with greater damage associated with a more extensive impairment (Reed & Squire, 1998). Anterograde amnesia provides evidence for the role of the hippocampus in the formation of long-lasting declarative memories, as damage to the hippocampus results in an inability to create this type of new memory. Similarly, temporally graded retrograde amnesia can be seen as providing further evidence for the importance of memory consolidation (Squire & Alvarez, 1995). A memory depends on the hippocampus until it is consolidated and transferred into a more durable form that is stored in the cortex. According to this theory, an amnesiac patient like H. M. could remember events from his remote past because those memories were fully consolidated and no longer depended on the hippocampus.

The classic amnesiac syndrome we have considered here is sometimes referred to as organic amnesia, and it is distinct from functional, or dissociative, amnesia. Functional amnesia involves a loss of memory that cannot be attributed to brain injury or any obvious brain disease and is typically classified as a mental disorder rather than a neurological disorder (Kihlstrom, 2005). The clinical profile of dissociative amnesia is very different from that of patients who suffer from amnesia due to brain damage or deterioration. Individuals who experience **dissociative amnesia** often have a history of trauma. Their amnesia is retrograde, encompassing autobiographical memories from a portion of their past. In an extreme version of this disorder, people enter a dissociative fugue state, in which they lose most or all of their autobiographical memories and their sense of personal identity. They may be found wandering in a new location, unaware of who they are and how they got there. Dissociative amnesia is controversial, as both the causes and existence of it have been called into question. The memory loss associated with dissociative amnesia is much less likely to be permanent than it is in organic amnesia.

Conclusion

Just as the case study of the mnemonist Shereshevsky illustrates what a life with a near perfect memory would be like, amnesiac patients show us what a life without memory would be like. Each of the mechanisms we discussed that explain everyday forgetting—encoding failures, decay, insufficient retrieval cues, interference, and intentional attempts to forget—help to keep us highly efficient, retaining the important information and for the most part, forgetting the unimportant. Amnesiac patients allow us a glimpse into what life would be like if we suffered from profound forgetting and perhaps show us that our everyday lapses in memory are not so bad after all.

Outside Resources

Web: Brain Case Study: Patient HM
https://bigpictureeducation.com/brain-case-study-patient-hm

Web: Self-experiment, Penny demo
http://www.indiana.edu/~p1013447/dictionary/penny.htm

Web: The Man Who Couldn’t Remember
http://www.pbs.org/wgbh/nova/body/corkin-hm-memory.html

Discussion Questions

1. Is forgetting good or bad? Do you agree with the authors that forgetting is an adaptive process? Why or why not?
2. Can we ever prove that something is forgotten? Why or why not?
3. Which of the five reasons for forgetting do you think explains the majority of incidences of forgetting? Why?
4. How is real-life amnesia different than amnesia that is portrayed on TV and in film?

Vocabulary

Anterograde amnesia
Inability to form new memories for facts and events after the onset of amnesia.

Consolidation
Process by which a memory trace is stabilized and transformed into a more durable form.

Decay
The fading of memories with the passage of time.

Declarative memory
Conscious memories for facts and events.

Dissociative amnesia
Loss of autobiographical memories from a period in the past in the absence of brain injury or disease.

Encoding
Process by which information gets into memory.

Interference
Other memories get in the way of retrieving a desired memory

Medial temporal lobes
Inner region of the temporal lobes that includes the hippocampus.

Retrieval
Process by which information is accessed from memory and utilized.

Retrograde amnesia
Inability to retrieve memories for facts and events acquired before the onset of amnesia.

Temporally graded retrograde amnesia
Inability to retrieve memories from just prior to the onset of amnesia with intact memory for more remote events.

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10

Eyewitness Testimony and Memory Biases

Cara Laney & Elizabeth F. Loftus

Eyewitnesses can provide very compelling legal testimony, but rather than recording experiences flawlessly, their memories are susceptible to a variety of errors and biases. They (like the rest of us) can make errors in remembering specific details and can even remember whole events that did not actually happen. In this module, we discuss several of the common types of errors, and what they can tell us about human memory and its interactions with the legal system.

Learning Objectives

- Describe the kinds of mistakes that eyewitnesses commonly make and some of the ways that this can impede justice.
- Explain some of the errors that are common in human memory.
- Describe some of the important research that has demonstrated human memory errors and their consequences.

What Is Eyewitness Testimony?

Eyewitness testimony is what happens when a person witnesses a crime (or accident, or other legally important event) and later gets up on the stand and recalls for the court all the details of the witnessed event. It involves a more complicated process than might initially be presumed. It includes what happens during the actual crime to facilitate or hamper witnessing, as well as everything that happens from the time the event is over to the later courtroom appearance. The eyewitness may be interviewed by the police and numerous lawyers, describe the perpetrator to several different people, and make an identification of the perpetrator, among other things.

What can happen to our memory from the time we witness an event to the retelling of that event later? What can influence how we remember, or misremember, highly significant events like a crime or accident? [Image: Robert Couse-Baker, https://goo.gl/OiPUmz, CC BY 2.0, https://goo.gl/BRvSA7]

Why Is Eyewitness Testimony an Important Area of Psychological Research?

When an eyewitness stands up in front of the court and describes what happened from her own perspective, this testimony can be extremely compelling—it is hard for those hearing this testimony to take it “with a grain of salt,” or otherwise adjust its power. But to what extent is this necessary?

There is now a wealth of evidence, from research conducted over several decades, suggesting that eyewitness testimony is probably the most persuasive form of evidence presented in court, but in many cases, its accuracy is dubious. There is also evidence that mistaken eyewitness evidence can lead to wrongful conviction—sending people to prison for years or decades, even to death row, for crimes they did not commit. Faulty eyewitness testimony has been implicated in at least 75% of DNA exoneration cases—more than any other cause (Garrett, 2011). In a particularly famous case, a man named Ronald Cotton was identified by a rape victim, Jennifer Thompson, as her rapist, and was found guilty and sentenced to life in prison. After more than 10 years, he was exonerated (and the real rapist identified) based on DNA evidence. For details on this case and other (relatively) lucky individuals whose false convictions were subsequently overturned with DNA evidence, see the Innocence Project website (**http://www.innocenceproject.org/**).

There is also hope, though, that many of the errors may be avoidable if proper precautions are taken during the investigative and judicial processes. Psychological science has taught us what some of those precautions might involve, and we discuss some of that science now.

Misinformation

Misinformation can be introduced into the memory of a witness between the time of seeing an event and reporting it later. Something as straightforward as which sort of traffic sign was in place at an intersection can be confused if subjects are exposed to erroneous information after the initial incident.

In an early study of eyewitness memory, undergraduate subjects first watched a slideshow depicting a small red car driving and then hitting a pedestrian (Loftus, Miller, & Burns, 1978). Some subjects were then asked leading questions about what had happened in the slides. For example, subjects were asked, “How fast was the car traveling when it passed the yield sign?” But this question was actually designed to be misleading, because the original slide included a stop sign rather than a yield sign.

Later, subjects were shown pairs of slides. One of the pair was the original slide containing the stop sign; the other was a replacement slide containing a yield sign. Subjects were asked which of the pair they had previously seen. Subjects who had been asked about the yield sign were likely to pick the slide showing the yield sign, even though they had originally seen the slide with the stop sign. In other words, the misinformation in the leading question led to inaccurate memory.

This phenomenon is called the misinformation effect, because the misinformation that subjects were exposed to after the event (here in the form of a misleading question) apparently contaminates subjects’ memories of what they witnessed. Hundreds of subsequent studies have demonstrated that memory can be contaminated by erroneous information that people are exposed to after they witness an event (see Frenda, Nichols, & Loftus, 2011; Loftus, 2005). The misinformation in these studies has led people to incorrectly remember everything from small but crucial details of a perpetrator's appearance to objects as large as a barn that wasn't there at all.

These studies have demonstrated that young adults (the typical research subjects in psychology) are often susceptible to misinformation, but that children and older adults can be even more susceptible (Bartlett & Memon, 2007; Ceci & Bruck, 1995). In addition, misinformation effects can occur easily, and without any intention to deceive (Allan & Gabbert, 2008). Even slight differences in the wording of a question can lead to misinformation effects. Subjects in one study were more likely to say yes when asked "Did you see the broken headlight?" than when asked "Did you see a broken headlight?" (Loftus, 1975).

Other studies have shown that misinformation can corrupt memory even more easily when it is encountered in social situations (Gabbert, Memon, Allan, & Wright, 2004). This is a problem particularly in cases where more than one person witnesses a crime. In these cases, witnesses tend to talk to one another in the immediate aftermath of the crime, including as they wait for police to arrive. But because different witnesses are different people with different perspectives, they are likely to see or notice different things, and thus remember different things, even when they witness the same event. So when they communicate about the crime later, they not only reinforce common memories for the event, they also contaminate each other's memories for the event (Gabbert, Memon, & Allan, 2003; Paterson & Kemp, 2006; Takarangi, Parker, & Garry, 2006).

The misinformation effect has been modeled in the laboratory. Researchers had subjects watch a video in pairs. Both subjects sat in front of the same screen, but because they wore differently polarized glasses, they saw two different versions of a video, projected onto a screen. So, although they were both watching the same screen, and believed (quite reasonably) that they were watching the same video, they were actually watching two different versions of the video (Garry, French, Kinzett, & Mori, 2008).

In the video, Eric the electrician is seen wandering through an unoccupied house and helping himself to the contents thereof. A total of eight details were different between the two videos. After watching the videos, the "co-witnesses" worked together on 12 memory test questions. Four of these questions dealt with details that were different in the two versions of the video, so subjects had the chance to influence one another. Then subjects worked individually on 20 additional memory test questions. Eight of these were for details that were different in the two videos. Subjects' accuracy was highly dependent on whether they had discussed the details previously. Their accuracy for items they had *not* previously discussed with their co-witness was 79%. But for items that they *had* discussed, their accuracy dropped markedly, to 34%. That is, subjects allowed their co-witnesses to corrupt their memories for what they had seen.

Identifying Perpetrators

In addition to correctly remembering many details of the crimes they witness, eyewitnesses often need to remember the faces and other identifying features of the perpetrators of those crimes. Eyewitnesses are often asked to describe that perpetrator to law enforcement and later to make identifications from books of mug shots or lineups. Here, too, there is a substantial body of research demonstrating that eyewitnesses can make serious, but often understandable and even predictable, errors (Caputo & Dunning, 2007; Cutler & Penrod, 1995).

In most jurisdictions in the United States, lineups are typically conducted with pictures, called **photo spreads**, rather than with actual people standing behind one-way glass (Wells, Memon, & Penrod, 2006). The eyewitness is given a set of small pictures of perhaps six or eight individuals who are dressed similarly and photographed in similar circumstances. One of these individuals is the police suspect, and the remainder are "**foils**" or "fillers" (people known to be innocent of the particular crime under investigation). If the eyewitness identifies the suspect, then the investigation of that suspect is likely to progress. If a witness identifies a foil or no one, then the police may choose to move their investigation in another direction.

Mistakes in identifying perpetrators can be influenced by a number of factors including poor viewing conditions, too little time to view the perpetrator, or too much delay from time of witnessing to identification.

This process is modeled in laboratory studies of eyewitness identifications. In these studies, research subjects witness a mock crime (often as a short video) and then are asked to make an identification from a photo or a live lineup. Sometimes the lineups are target present, meaning that the perpetrator from the mock crime is actually in the lineup, and sometimes they are target absent, meaning that the lineup is made up entirely of foils. The subjects, or **mock witnesses**, are given some instructions and asked to pick the perpetrator out of the lineup. The particular details of the witnessing experience, the instructions, and the lineup members can all influence the extent to which the mock witness is likely to pick the perpetrator out of the lineup, or indeed to make any selection at all. Mock witnesses (and indeed real witnesses) can make errors in two different ways. They can fail to pick the perpetrator out of a target present lineup (by picking a foil or by neglecting to make a selection), or they can pick a foil in a target absent lineup (wherein the only correct choice is to not make a selection).

Some factors have been shown to make eyewitness identification errors particularly likely. These include poor vision or viewing conditions during the crime, particularly stressful witnessing experiences, too little time to view the perpetrator or perpetrators, too much delay between witnessing and identifying, and being asked to identify a perpetrator from a race other than one's own (Bornstein, Deffenbacher, Penrod, & McGorty, 2012; Brigham, Bennett, Meissner, & Mitchell, 2007; Burton, Wilson, Cowan, & Bruce, 1999; Deffenbacher, Bornstein, Penrod, & McGorty, 2004).

It is hard for the legal system to do much about most of these problems. But there are some things that the justice system can do to help lineup identifications "go right." For example, investigators can put together high-quality, fair lineups. A fair lineup is one in which the suspect and each of the foils is equally likely to be chosen by someone who has read an eyewitness description of the perpetrator but who did not actually witness the crime (Brigham, Ready, & Spier, 1990). This means that no one in the lineup should "stick out," and that everyone should match the description given by the eyewitness. Other important recommendations that have come out of this research include better ways to conduct lineups, "double blind" lineups, unbiased instructions for witnesses, and conducting lineups in a sequential fashion (see Technical Working Group for Eyewitness Evidence, 1999; Wells et al., 1998; Wells & Olson, 2003).

Kinds of Memory Biases

Memory is also susceptible to a wide variety of other biases and errors. People can forget events that happened to them and people they once knew. They can mix up details across time and place. They can even remember whole complex events that never happened at all. Importantly, these errors, once made, can be very hard to unmake. A memory is no less "memorable" just because it is wrong.

Some small memory errors are commonplace, and you have no doubt experienced many of them. You set down your keys without paying attention, and then cannot find them later when you go to look for them. You try to come up with a person's name but cannot find it, even though you have the sense that it is right at the tip of your tongue (psychologists actually call this the tip-of-the-tongue effect, or TOT) (Brown, 1991).

For most of our experiences schematas are a benefit and help with information overload. However, they may make it difficult or impossible to recall certain details of a situation later. Do you recall the library as it actually was or the library as approximated by your library schemata? [Dan Kleinman, https://goo.gl/07xyDD, CC BY 2.0, https://goo.gl/BRvSA7]

Other sorts of memory biases are more complicated and longer lasting. For example, it turns out that our expectations and beliefs about how the world works can have huge influences on our memories. Because many aspects of our everyday lives are full of redundancies, our memory systems take advantage of the recurring patterns by forming and using **schemata**, or memory templates (Alba & Hasher, 1983; Brewer & Treyens, 1981). Thus, we know to expect that a library will have shelves and tables and librarians, and so we don't have to spend energy noticing these at the time. The result of this lack of attention, however, is that one is likely to remember schema-consistent information (such as tables), and to remember them in a rather generic way, whether or not they were actually present.

False Memory

Some memory errors are so "large" that they almost belong in a class of their own: **false memories**. Back in the early 1990s a pattern emerged whereby people would go into therapy for depression and other everyday problems, but over the course of the therapy develop memories for violent and horrible victimhood (Loftus & Ketcham, 1994). These patients' therapists claimed that the patients were recovering genuine memories of real childhood abuse, buried deep in their minds for years or even decades. But some experimental psychologists believed that the memories were instead likely to be false—created in therapy. These researchers then set out to see whether it would indeed be possible for wholly false memories to be created by procedures similar to those used in these patients' therapy.

In early false memory studies, undergraduate subjects' family members were recruited to provide events from the students' lives. The student subjects were told that the researchers had talked to their family members and learned about four different events from their childhoods. The researchers asked if the now undergraduate students remembered each of these four events—introduced via short hints. The subjects were asked to write about each of the four events in a booklet and then were interviewed two separate times. The trick was that one of the events came from the researchers rather than the family (and the family had actually assured the researchers that this event had *not* happened to the subject). In the first such study, this researcher-introduced event was a story about being lost in a shopping mall and rescued by an older adult. In this study, after just being asked whether they remembered these events occurring on three separate occasions, a quarter of subjects came to believe that they had indeed been lost in the mall (Loftus & Pickrell, 1995). In subsequent studies, similar procedures were used to get subjects to believe that they nearly drowned and had been rescued by a lifeguard, or that they had spilled punch on the bride's parents at a family wedding, or that they had been attacked by a vicious animal as a child, among other events (Heaps & Nash, 1999; Hyman, Husband, & Billings, 1995; Porter, Yuille, & Lehman, 1999).

More recent false memory studies have used a variety of different manipulations to produce false memories in substantial minorities and even occasional majorities of manipulated subjects (Braun, Ellis, & Loftus, 2002; Lindsay, Hagen, Read, Wade, & Garry, 2004; Mazzoni, Loftus, Seitz, & Lynn, 1999; Seamon, Philbin, & Harrison, 2006; Wade, Garry, Read, & Lindsay, 2002). For example, one group of researchers used a mock-advertising study, wherein subjects were asked to review (fake) advertisements for Disney vacations, to convince subjects that they had once met the character Bugs Bunny at Disneyland—an impossible false memory because Bugs is a Warner Brothers character (Braun et al., 2002). Another group of researchers photoshopped childhood photographs of their subjects into a hot air balloon picture and then asked the subjects to try to remember and describe their hot air balloon experience (Wade et al., 2002). Other researchers gave subjects unmanipulated class photographs from their childhoods along with a fake story about a class prank, and thus enhanced the likelihood that subjects would falsely remember the prank (Lindsay et al., 2004).

Using a false feedback manipulation, we have been able to persuade subjects to falsely remember having a variety of childhood experiences. In these studies, subjects are told (falsely) that a powerful computer system has analyzed questionnaires that they completed previously and has concluded that they had a particular experience years earlier. Subjects apparently believe what the computer says about them and adjust their memories to match this new information. A variety of different false memories have been implanted in this way. In some studies, subjects are told they once got sick on a particular food (Bernstein, Laney, Morris, & Loftus, 2005). These memories can then spill out into other aspects of subjects' lives, such that they often become less interested in eating that food in the future (Bernstein & Loftus, 2009b). Other false memories implanted with this methodology include having an unpleasant experience with the character Pluto at Disneyland and witnessing physical violence between one's parents (Berkowitz, Laney, Morris, Garry, & Loftus, 2008; Laney & Loftus, 2008).

Importantly, once these false memories are implanted—whether through complex methods or simple ones—it is extremely difficult to tell them apart from true memories (Bernstein & Loftus, 2009a; Laney & Loftus, 2008).

Conclusion

To conclude, eyewitness testimony is very powerful and convincing to jurors, even though it is not particularly reliable. Identification errors occur, and these errors can lead to people being falsely accused and even convicted. Likewise, eyewitness memory can be corrupted by leading questions, misinterpretations of events, conversations with co-witnesses, and their own expectations for what should have happened. People can even come to remember whole events that never occurred.

The problems with memory in the legal system are real. But what can we do to start to fix them? A number of specific recommendations have already been made, and many of these are in the process of being implemented (e.g., Steblay & Loftus, 2012; Technical Working Group for Eyewitness Evidence, 1999; Wells et al., 1998). Some of these recommendations are aimed at specific legal procedures, including when and how witnesses should be interviewed, and how lineups should be constructed and conducted. Other recommendations call for appropriate education (often in the form of expert witness testimony) to be provided to jury members and others tasked with assessing eyewitness memory. Eyewitness testimony can be of great value to the legal system, but decades of research now argues that this testimony is often given far more weight than its accuracy justifies.

Outside Resources

Video 1: Eureka Foong's - The Misinformation Effect. This is a student-made video illustrating this phenomenon of altered memory. It was one of the winning entries in the 2014 Noba Student Video Award.
https://www.youtube.com/watch?v=iMPIWkFtd88

Video 2: Ang Rui Xia & Ong Jun Hao's - The Misinformation Effect. Another student-made video exploring the misinformation effect. Also an award winner from 2014.
https://www.youtube.com/watch?v=gsn9iKmOJLQ

Discussion Questions

1. Imagine that you are a juror in a murder case where an eyewitness testifies. In what ways might your knowledge of memory errors affect your use of this testimony?
2. How true to life do you think television shows such as CSI or Law & Order are in their portrayals of eyewitnesses?
3. Many jurisdictions in the United States use “show-ups,” where an eyewitness is brought to a suspect (who may be standing on the street or in handcuffs in the back of a police car) and asked, “Is this the perpetrator?” Is this a good or bad idea, from a psychological perspective? Why?

Vocabulary

False memories
Memory for an event that never actually occurred, implanted by experimental manipulation or other means.

Foils
Any member of a lineup (whether live or photograph) other than the suspect.

Misinformation effect
A memory error caused by exposure to incorrect information between the original event (e.g., a crime) and later memory test (e.g., an interview, lineup, or day in court).

Mock witnesses
A research subject who plays the part of a witness in a study.

Photo spreads
A selection of normally small photographs of faces given to a witness for the purpose of identifying a perpetrator.

Schema (plural: schemata)
A memory template, created through repeated exposure to a particular class of objects or events.

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11

Categories and Concepts

Gregory Murphy

People form mental concepts of categories of objects, which permit them to respond appropriately to new objects they encounter. Most concepts cannot be strictly defined but are organized around the “best” examples or prototypes, which have the properties most common in the category. Objects fall into many different categories, but there is usually a most salient one, called the basic-level category, which is at an intermediate level of specificity (e.g., chairs, rather than furniture or desk chairs). Concepts are closely related to our knowledge of the world, and people can more easily learn concepts that are consistent with their knowledge. Theories of concepts argue either that people learn a summary description of a whole category or else that they learn exemplars of the category. Recent research suggests that there are different ways to learn and represent concepts and that they are accomplished by different neural systems.

Learning Objectives

- Understand the problems with attempting to define categories.
- Understand typicality and fuzzy category boundaries.
- Learn about theories of the mental representation of concepts.
- Learn how knowledge may influence concept learning.

Introduction

Consider the following set of objects: some dust, papers, a computer monitor, two pens, a cup, and an orange. What do these things have in common? Only that they all happen to be on my desk as I write this. This set of things can be considered a **category**, a set of objects that can be treated as equivalent in some way. But, most of our categories seem much more informative—they share many properties. For example, consider the following categories: trucks, wireless devices, weddings, psychopaths, and trout. Although the objects in a given category are different from one another, they have many commonalities. When you know something is a truck, you know quite a bit about it. The psychology of categories concerns how people learn, remember, and use informative categories such as trucks or psychopaths.

Although you've (probably) never seen this particular truck before, you know a lot about it because of the knowledge you've accumulated in the past about the features in the category of trucks. [Image: CC0 Public Domain, https://goo.gl/m25gce]

The mental representations we form of categories are called **concepts**. There is a category of trucks in the world, and I also have a concept of trucks in my head. We assume that people's concepts correspond more or less closely to the actual category, but it can be useful to distinguish the two, as when someone's concept is not really correct.

Concepts are at the core of intelligent behavior. We expect people to be able to know what to do in new situations and when confronting new objects. If you go into a new classroom and see chairs, a blackboard, a projector, and a screen, you know what these things are and how they will be used. You'll sit on one of the chairs and expect the instructor to write on the blackboard or project something onto the screen. You do this *even if you have never seen any of these particular objects before*, because you have concepts of classrooms, chairs, projectors, and so forth, that tell you what they are and what you're supposed to do with them. Furthermore, if someone tells you a new fact about the projector—for example, that it has a halogen bulb—you are likely to extend this fact to other projectors you encounter. In short, concepts allow you to extend what you have learned about a limited number of objects to a potentially infinite set of entities.

You know thousands of categories, most of which you have learned without careful study or instruction. Although this accomplishment may seem simple, we know that it isn't, because it is difficult to program computers to solve such intellectual tasks. If you teach a learning program that a robin, a swallow, and a duck are all birds, it may not recognize a cardinal or peacock as a bird. As we'll shortly see, the problem is that objects in categories are often surprisingly diverse.

Simpler organisms, such as animals and human infants, also have concepts (Mareschal, Quinn, & Lea, 2010). Squirrels may have a concept of predators, for example, that is specific to their own lives and experiences. However, animals likely have many fewer concepts and cannot understand complex concepts such as mortgages or musical instruments.

Nature of Categories

Traditionally, it has been assumed that categories are *well-defined*. This means that you can give a definition that specifies what is in and out of the category. Such a definition has two parts. First, it provides the *necessary features* for category membership: What must objects have in order to be in it? Second, those features must be *jointly sufficient* for membership: If an object has those features, then it is in the category. For example, if I defined a dog as a four-legged animal that barks, this would mean that every dog is four-legged, an animal, and barks, and also that anything that has all those properties is a dog.

Here is a very good dog, but one that does not fit perfectly into a well-defined category where all dogs have four legs. [Image: State Farm, https://goo.gl/KHtu6N, CC BY 2.0, https://goo.gl/BRvSA7]

Unfortunately, it has not been possible to find definitions for many familiar categories. Definitions are neat and clear-cut; the world is messy and often unclear. For example, consider our definition of dogs. In reality, not all dogs have four legs; not all dogs bark. I knew a dog that lost her bark with age (this was an improvement); no one doubted that she was still a dog. It is often possible to find some necessary features (e.g., all dogs have blood and breathe), but these features are generally not sufficient to determine category membership (you also have blood and breathe but are not a dog).

Even in domains where one might expect to find clear-cut definitions, such as science and law, there are often problems. For example, many people were upset when Pluto was downgraded from its status as a planet to a dwarf planet in 2006. Upset turned to outrage when they discovered that there was no hard-and-fast definition of planethood: “Aren’t these astronomers scientists? Can’t they make a simple definition?” In fact, they couldn’t. After an astronomical organization tried to make a definition for planets, a number of astronomers complained that it might not include accepted planets such as Neptune and refused to use it. If everything looked like our Earth, our moon, and our sun, it would be easy to give definitions of planets, moons, and stars, but the universe has sadly not conformed to this ideal.

Fuzzy Categories

Borderline Items

Experiments also showed that the psychological assumptions of well-defined categories were not correct. Hampton (1979) asked subjects to judge whether a number of items were in different categories. He did not find that items were either clear members or clear nonmembers. Instead, he found many items that were just barely considered category members and others that were just barely not members, with much disagreement among subjects. Sinks were barely considered as members of the kitchen utensil category, and sponges were barely excluded. People just included seaweed as a vegetable and just barely excluded tomatoes and gourds. Hampton found that members and nonmembers formed a continuum, with no obvious break in people’s membership judgments. If categories were well defined, such examples should be very rare. Many studies since then have found such *borderline members* that are not clearly in or clearly out of the category.

Furniture	Fruit
chair	orange
table	banana
desk	pear
bookcase	plum
lamp	strawberry
cushion	pineapple
rug	lemon
stove	honeydew
picture	date
vase	tomato

Table 1. Examples of two categories, with members ordered by typicality (from Rosch & Mervis, 1975)

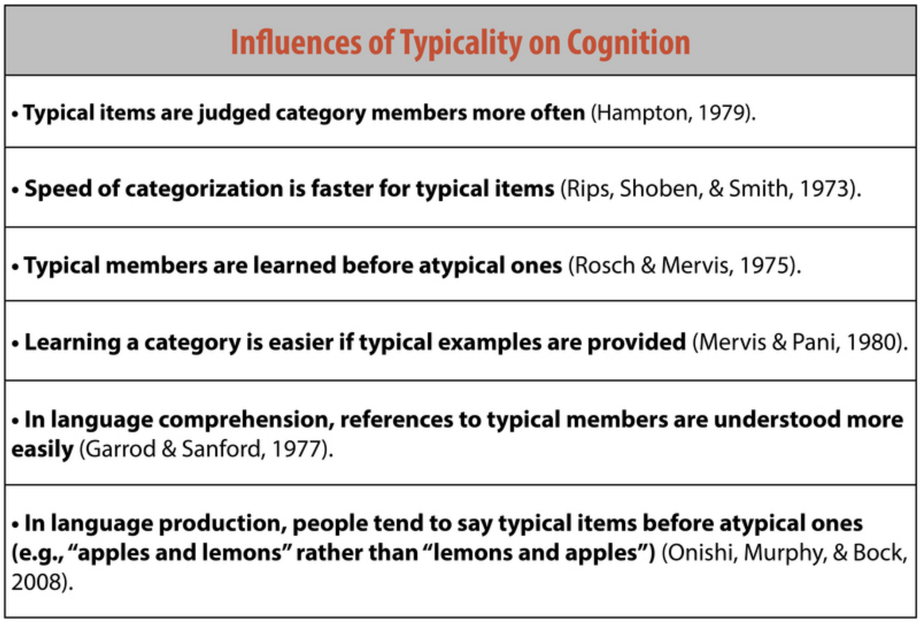
McCloskey and Glucksberg (1978) found further evidence for borderline membership by asking people to judge category membership twice, separated by two weeks. They found that when people made repeated category judgments such as “Is an olive a fruit?” or “Is a sponge a kitchen utensil?” they changed their minds about borderline items—up to 22 percent of the time. So, not only do people disagree with one another about borderline items, they disagree with themselves! As a result, researchers often say that categories are *fuzzy*, that is, they have unclear boundaries that can shift over time.

Typicality

A related finding that turns out to be most important is that even among items that clearly are in a category, some seem to be "better" members than others (Rosch, 1973). Among birds, for example, robins and sparrows are very typical. In contrast, ostriches and penguins are very *atypical* (meaning not typical). If someone says, "There's a bird in my yard," the image you have will be of a smallish passerine bird such as a robin, not an eagle or hummingbird or turkey.

You can find out which category members are typical merely by asking people. Table 1 shows a list of category members in order of their rated typicality. Typicality is perhaps the most important variable in predicting how people interact with categories. The following text box is a partial list of what typicality influences.

We can understand the two phenomena of borderline members and typicality as two sides of the same coin. Think of the most typical category member: This is often called the category *prototype*. Items that are less and less similar to the prototype become less and less typical. At some point, these less typical items become so atypical that you start to doubt whether they are in the category at all. Is a rug really an example of furniture? It's in the home like chairs and tables, but it's also different from most furniture in its structure and use. From day to day, you might change your mind as to whether this atypical example is in or out of the



Influences of Typicality on Cognition

- **Typical items are judged category members more often** (Hampton, 1979).
- **Speed of categorization is faster for typical items** (Rips, Shoben, & Smith, 1973).
- **Typical members are learned before atypical ones** (Rosch & Mervis, 1975).
- **Learning a category is easier if typical examples are provided** (Mervis & Pani, 1980).
- **In language comprehension, references to typical members are understood more easily** (Garrod & Sanford, 1977).
- **In language production, people tend to say typical items before atypical ones (e.g., "apples and lemons" rather than "lemons and apples")** (Onishi, Murphy, & Bock, 2008).

Text Box 1

category. So, changes in typicality ultimately lead to borderline members.

Source of Typicality

Intuitively, it is not surprising that robins are better examples of birds than penguins are, or that a table is a more typical kind of furniture than is a rug. But given that robins and penguins are known to be birds, why should one be more typical than the other? One possible answer is the frequency with which we encounter the object: We see a lot more robins than penguins, so they must be more typical. Frequency does have some effect, but it is actually not the most important variable (Rosch, Simpson, & Miller, 1976). For example, I see both rugs and tables every single day, but one of them is much more typical as furniture than the other.

The best account of what makes something typical comes from Rosch and Mervis's (1975) *family resemblance theory*. They proposed that items are likely to be typical if they (a) have the features that are frequent in the category and (b) do not have features frequent in other categories. Let's compare two extremes, robins and penguins. Robins are small flying birds that sing, live in nests in trees, migrate in winter, hop around on your lawn, and so on. Most of these properties are found in many other birds. In contrast, penguins do not fly, do not sing, do not live in nests or in trees, do not hop around on your lawn. Furthermore, they have properties that are common in other categories, such as swimming expertly and having wings that look and act like fins. These properties are more often found in fish than in birds.

According to Rosch and Mervis, then, it is not because a robin is a very common bird that makes it typical. Rather, it is because the robin has the shape, size, body parts, and behaviors that are very common among birds—and not common among fish, mammals, bugs, and so forth.

In a classic experiment, Rosch and Mervis (1975) made up two new categories, with arbitrary features. Subjects viewed example after example and had to learn which example was in which category. Rosch and Mervis constructed some items that had features that were common in the category and other items that had features less

When you think of "bird," how closely does the robin resemble your general figure? [Image: CC0 Public Domain, https://goo.gl/m25gce] common in the category. The subjects learned the first type of item before they learned the second type. Furthermore, they then rated the items with common features as more typical. In another experiment, Rosch and Mervis constructed items that differed in how many features were shared with a *different* category. The more features were shared, the longer it took subjects to learn which category the item was in. These experiments, and many later studies, support both parts of the family resemblance theory.

Category Hierarchies

Many important categories fall into *hierarchies*, in which more concrete categories are nested inside larger, abstract categories. For example, consider the categories: brown bear, bear, mammal, vertebrate, animal, entity. Clearly, all brown bears are bears; all bears are mammals; all mammals are vertebrates; and so on. Any given object typically does not fall into just one category—it could be in a dozen different categories, some of which are structured in this hierarchical manner. Examples of biological categories come to mind most easily, but within the realm of human artifacts, hierarchical structures can readily be found: desk chair, chair, furniture, artifact, object.

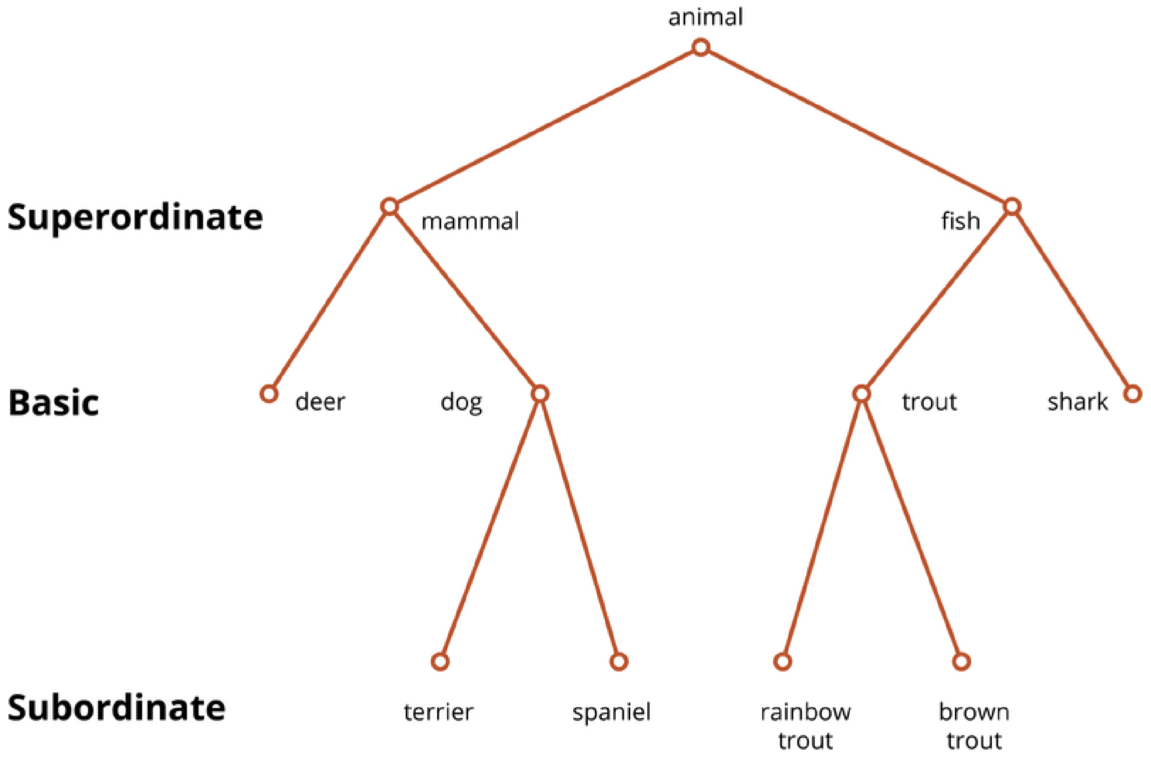


Figure 1. This is a highly simplified illustration of hierarchically organized categories, with the superordinate, basic, and subordinate levels labeled. Keep in mind that there may be even more specific subordinates (e.g., wire-haired terriers) and more general superordinates (e.g., living thing)

Brown (1958), a child language researcher, was perhaps the first to note that there seems to be a preference for which category we use to label things. If your office desk chair is in the way, you'll probably say, "Move that chair," rather than "Move that desk chair" or "piece of furniture." Brown thought that the use of a single, consistent name probably helped children to learn the name for things. And, indeed, children's first labels for categories tend to be exactly those names that adults prefer to use (Anglin, 1977).

This preference is referred to as a preference for the **basic level of categorization**, and it was first studied in detail by Eleanor Rosch and her students (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). The basic level represents a kind of Goldilocks effect, in which the category used for something is not too small (northern brown bear) and not too big (animal), but is just right (bear). The simplest way to identify an object's basic-level category is to discover how it would be labeled in a neutral situation. Rosch et al. (1976) showed subjects pictures and asked them to provide the first name that came to mind. They found that 1,595 names were at the basic level, with 14 more specific names (*subordinates*) used. Only once did anyone use a more general name (*superordinate*). Furthermore, in printed text, basic-level labels are much more frequent than most subordinate or superordinate labels (e.g., Wisniewski & Murphy, 1989).

The preference for the basic level is not merely a matter of labeling. Basic-level categories are usually easier to learn. As Brown noted, children use these categories first in language learning, and superordinates are especially difficult for children to fully acquire.**[1]** People are faster at identifying objects as members of basic-level categories (Rosch et al., 1976).

Rosch et al. (1976) initially proposed that basic-level categories cut the world at its joints, that is, merely reflect the big differences between categories like chairs and tables or between cats and mice that exist in the world. However, it turns out that which level is basic is not universal. North Americans are likely to use names like *tree, fish*, and *bird* to label natural objects. But people in less industrialized societies seldom use these labels and instead use more specific words, equivalent to *elm, trout,* and *finch* (Berlin, 1992). Because Americans and many other people living in industrialized societies know so much less than our ancestors did about the natural world, our basic level has "moved up" to what would have been the superordinate level a century ago. Furthermore, experts in a domain often have a preferred level that is more specific than that of non-experts. Birdwatchers see sparrows rather than just birds, and carpenters see roofing hammers rather than just hammers (Tanaka & Taylor, 1991). This all suggests that the preferred level is not (only) based on how different categories are in the world, but that people's knowledge and interest in the categories has an important effect.

One explanation of the basic-level preference is that basic-level categories are more *differentiated:* The category members are similar to one another, but they are different from members of other categories (Murphy & Brownell, 1985; Rosch et al., 1976). (The alert reader will note a similarity to the explanation of typicality I gave above. However, here we're talking about the entire category and not individual members.) Chairs are pretty similar to one another, sharing a lot of features (legs, a seat, a back, similar size and shape); they also don't share that many features with other furniture. Superordinate categories are not as useful because their members are not very similar to one another. What features are common to most furniture? There are very few. Subordinate categories are not as useful, because they're very similar to other categories: Desk chairs are quite similar to dining room chairs and easy chairs. As a result, it can be difficult to decide which subordinate category an object is in (Murphy & Brownell, 1985). Experts can differ from novices in which categories are the most differentiated, because they know different things about the categories, therefore changing how similar the categories are.

> [1] This is a controversial claim, as some say that infants learn superordinates before anything else (Mandler, 2004). However, if true, then it is very puzzling that older children have great difficulty learning the correct meaning of words for superordinates, as well as in learning artificial superordinate categories (Horton & Markman, 1980; Mervis, 1987). However, it seems fair to say that the answer to this question is not yet fully known.

Theories of Concept Representation

Now that we know these facts about the psychology of concepts, the question arises of how concepts are mentally represented. There have been two main answers. The first, somewhat confusingly called the *prototype theory* suggests that people have a *summary representation* of the category, a mental description that is meant to apply to the category as a whole. (The significance of *summary* will become apparent when the next theory is described.) This description can be represented as a set of *weighted features* (Smith & Medin, 1981). The features are weighted by their frequency in the category. For the category of birds, having wings and feathers would have a very high weight; eating worms would have a lower weight; living in Antarctica would have a lower weight still, but not zero, as some birds do live there.

The idea behind prototype theory is that when you learn a category, you learn a general description that applies to the category as a whole: Birds have wings and usually fly; some eat worms; some swim underwater to catch fish. People can state these generalizations, and sometimes we learn about categories by reading or hearing such statements ("The kimodo dragon can grow to be 10 feet long").

If you were asked, "What kind of animal is this?" according to prototype theory, you would consult your summary representations of different categories and then select the one that is most similar to this image—probably a lizard! [Image: Adhi Rachdian, https://goo.gl/dQyUwf, CC BY 2.0, https://goo.gl/BRvSA7]

When you try to classify an item, you see how well it matches that weighted list of features. For example, if you saw something with wings and feathers fly onto your front lawn and eat a worm, you could (unconsciously) consult your concepts and see which ones contained the features you observed. This example possesses many of the highly weighted bird features, and so it should be easy to identify as a bird.

This theory readily explains the phenomena we discussed earlier. Typical category members have more, higher-weighted features. Therefore, it is easier to match them to your conceptual representation. Less typical items have fewer or lower-weighted features (and they may have features of other concepts). Therefore, they don't match your representation as well. This makes people less certain in classifying such items. Borderline items may have features in common with multiple categories or not be very close to any of them. For example, edible seaweed does not have many of the common features of vegetables but also is not close to any other food concept (meat, fish, fruit, etc.), making it hard to know what kind of food it is.

A very different account of concept representation is the *exemplar theory* (exemplar being a fancy name for an example; Medin & Schaffer, 1978). This theory denies that there is a summary representation. Instead, the theory claims that your concept of vegetables is remembered examples of vegetables you have seen. This could of course be hundreds or thousands of exemplars over the course of your life, though we don't know for sure how many exemplars you actually remember.

How does this theory explain classification? When you see an object, you (unconsciously) compare it to the exemplars in your memory, and you judge how similar it is to exemplars in different categories. For example, if you see some object on your plate and want to identify it, it will probably activate memories of vegetables, meats, fruit, and so on. In order to categorize this object, you calculate how similar it is to each exemplar in your memory. These similarity scores are added up for each category. Perhaps the object is very similar to a large number of vegetable exemplars, moderately similar to a few fruit, and only minimally similar to some exemplars of meat you remember. These similarity scores are compared, and the category with the highest score is chosen.**[2]**

Why would someone propose such a theory of concepts? One answer is that in many experiments studying concepts, people learn concepts by seeing exemplars over and over again until they learn to classify them correctly. Under such conditions, it seems likely that people eventually memorize the exemplars (Smith & Minda, 1998). There is also evidence that *close similarity* to well-remembered objects has a large effect on classification. Allen and Brooks (1991) taught people to classify items by following a rule. However, they also had their subjects study the items, which were richly detailed. In a later test, the experimenters gave people new items that were very similar to one of the old items but were in a different category. That is, they changed one property so that the item no longer followed the rule. They discovered that people were often fooled by such items. Rather than following the category rule they had been taught, they seemed to recognize the new item as being very similar to an old one and so put it, incorrectly, into the same category.

Many experiments have been done to compare the prototype and exemplar theories. Overall, the exemplar theory seems to have won most of these comparisons. However, the experiments are somewhat limited in that they usually involve a small number of exemplars that people view over and over again. It is not so clear that exemplar theory can explain real-world classification in which people do not spend much time learning individual items (how much time do you spend studying squirrels? or chairs?). Also, given that some part of our knowledge of categories is learned through general statements we read or hear, it seems that there must be room for a summary description separate from exemplar memory.

Many researchers would now acknowledge that concepts are represented through multiple cognitive systems. For example, your knowledge of dogs may be in part through general descriptions such as “dogs have four legs.” But you probably also have strong memories of some exemplars (your family dog, Lassie) that influence your categorization. Furthermore, some categories also involve rules (e.g., a strike in baseball). How these systems work together is the subject of current study.

[2] Actually, the decision of which category is chosen is more complex than this, but the details are beyond this discussion.

Knowledge

The final topic has to do with how concepts fit with our broader knowledge of the world. We have been talking very generally about people learning the features of concepts. For example, they see a number of birds and then learn that birds generally have wings, or perhaps they remember bird exemplars. From this perspective, it makes no difference what those exemplars or features are—people just learn them. But consider two possible concepts of buildings and their features in Table 2.

Donker	**Blegdav**
has thick windows	has steel windows
is red	is purple
divers live there	farmers live there
is under water	is in the desert
get there by submarine	get there by submarine
has fish as pets	has polar bears as pets

Table 2. Examples of two fictional concepts

Imagine you had to learn these two concepts by seeing exemplars of them, each exemplar having some of the features listed for the concept (as well as some idiosyncratic features). Learning the donker concept would be pretty easy. It seems to be a kind of underwater building, perhaps for deep-sea explorers. Its features seem to go together. In contrast, the blegdav doesn't really make sense. If it's in the desert, how can you get there by submarine, and why do they have polar bears as pets? Why would farmers live in the desert or use submarines? What good would steel windows do in such a building? This concept seems peculiar. In fact, if people are asked to learn new concepts that make sense, such as donkers, they learn them quite a bit faster than concepts such as blegdavs that don't make sense (Murphy & Allopenna, 1994). Furthermore, the features that seem connected to one another (such as being underwater and getting there by submarine) are learned better than features that don't seem related to the others (such as being red).

Such effects demonstrate that when we learn new concepts, we try to connect them to the knowledge we already have about the world. If you were to learn about a new animal that doesn't seem to eat or reproduce, you would be very puzzled and think that you must have gotten something wrong. By themselves, the prototype and exemplar theories don't predict this. They simply say that you learn descriptions or exemplars, and they don't put any constraints on what those descriptions or exemplars are. However, the *knowledge approach* to concepts emphasizes that concepts are meant to tell us about real things in the world, and so our knowledge of the world is used in learning and thinking about concepts.

We can see this effect of knowledge when we learn about new pieces of technology. For example, most people could easily learn about tablet computers (such as iPads) when they were first introduced by drawing on their knowledge of laptops, cell phones, and related technology. Of course, this reliance on past knowledge can also lead to errors, as when people don't learn about features of their new tablet that weren't present in their cell phone or expect the tablet to be able to do something it can't.

One important aspect of people's knowledge about categories is called psychological essentialism (Gelman, 2003; Medin & Ortony, 1989). People tend to believe that some categories—most notably natural kinds such as animals, plants, or minerals—have an underlying property that is found only in that category and that causes its other features. Most categories don't actually have essences, but this is sometimes a firmly held belief. For example, many people will state that there is something about dogs, perhaps some specific gene or set of genes, that all dogs have and that makes them bark, have fur, and look the way they do. Therefore, decisions about whether something is a dog do not depend only on features that you can easily see but also on the assumed presence of this cause.

Belief in an essence can be revealed through experiments describing fictional objects. Keil (1989) described to adults and children a fiendish operation in which someone took a raccoon, dyed its hair black with a white stripe down the middle, and implanted a "sac of super-smelly yucky stuff" under its tail. The subjects were shown a picture of a skunk and told that this is now what the animal looks like. What is it? Adults and children over the age of 4 all agreed that the animal is still a raccoon. It may look and even act like a skunk, but a raccoon cannot change its stripes (or whatever!)—it will always be a raccoon.

Although it may seem natural that different species have an unchangeable "essence," consider evolution and everything's development from common ancestors. [Image: Marc Dragiewicz, https://goo.gl/E9v4eR, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

Importantly, the same effect was not found when Keil described a coffeepot that was operated on to look like and function as a bird feeder. Subjects agreed that it was now a bird feeder. Artifacts don't have an essence.

Signs of essentialism include (a) objects are believed to be either in or out of the category, with no in-between; (b) resistance to change of category membership or of properties connected to the essence; and (c) for living things, the essence is passed on to progeny.

Essentialism is probably helpful in dealing with much of the natural world, but it may be less helpful when it is applied to humans. Considerable evidence suggests that people think of gender, racial, and ethnic groups as having essences, which serves to emphasize the difference between groups and even justify discrimination (Hirschfeld, 1996). Historically, group differences were described by inheriting the blood of one's family or group. "Bad blood" was not just an expression but a belief that negative properties were inherited and could not be changed. After all, if it is in the nature of "those people" to be dishonest (or clannish or athletic ...), then that could hardly be changed, any more than a raccoon can change into a skunk.

Research on categories of people is an exciting ongoing enterprise, and we still do not know as much as we would like to about how concepts of different kinds of people are learned in childhood and how they may (or may not) change in adulthood. Essentialism doesn't apply only to person categories, but it is one important factor in how we think of groups.

Conclusion

Concepts are central to our everyday thought. When we are planning for the future or thinking about our past, we think about specific events and objects in terms of their categories. If you're visiting a friend with a new baby, you have some expectations about what the baby will do, what gifts would be appropriate, how you should behave toward it, and so on. Knowing about the category of babies helps you to effectively plan and behave when you encounter this child you've never seen before.

Learning about those categories is a complex process that involves seeing exemplars (babies), hearing or reading general descriptions ("Babies like black-and-white pictures"), general knowledge (babies have kidneys), and learning the occasional rule (all babies have a rooting reflex). Current research is focusing on how these different processes take place in the brain. It seems likely that these different aspects of concepts are accomplished by different neural structures (Maddox & Ashby, 2004).

Another interesting topic is how concepts differ across cultures. As different cultures have different interests and different kinds of interactions with the world, it seems clear that their concepts will somehow reflect those differences. On the other hand, the structure of categories in the world also imposes a strong constraint on what kinds of categories are actually useful. Some researchers have suggested that differences between Eastern and Western modes of thought have led to qualitatively different kinds of concepts (e.g., Norenzayan, Smith, Kim, & Nisbett, 2002). Although such differences are intriguing, we should also remember that different cultures seem to share common categories such as chairs, dogs, parties, and jars, so the differences may not be as great as suggested by experiments designed to detect cultural effects. The interplay of culture, the environment, and basic cognitive processes in establishing concepts has yet to be fully investigated.

Outside Resources

Debate: The debate about Pluto and the definition of planet is an interesting one, as it illustrates the difficulty of arriving at definitions even in science. The Planetary Science Institute's website has a series of press releases about the Pluto debate, including reactions from astronomers, while it happened.
http://www.psi.edu

Image Search: It can be interesting to get a pictorial summary of how much diversity there is among category members. If you do an image search for familiar categories such as houses, dogs, weddings, telephones, fruit, or whatever, you can get a visual display on a single page of the category structure. Of course, the results are probably biased, as people do not just randomly upload pictures of dogs or fruit, but it nonetheless will likely reveal the typicality structure, as most of the pictures will be of typical exemplars, and the atypical ones will stand out. (This activity will also demonstrate the phenomenon of ambiguity in language, as a search for "house" will yield some pictures of the TV character House, M.D. However, that is a lesson for a different module.)
https://www.google.com/

Self-test: If you would like to run your own category-learning experiment, you can do so by following the link below. It works either in-browser or by download. When downloaded, users can put in their own stimuli to categorize.
http://cognitrn.psych.indiana.edu/CogSciSoftware/Categorization/index.html

Software: Self-test Categorization Applet - This software allows you to conduct your own categorization experiment.
http://cognitrn.psych.indiana.edu/CogSciSoftware/Categorization/index.html

Web: A Compendium of Category and Concept Activities and Worksheets - This website contains all types of printable worksheets and activities on how to categorize concepts. It includes word searches, picture sorts, and more.
https://freelanguagestuff.com/category/

Web: An interesting article at Space.com argues (I believe correctly) that the term planet will not and should not be defined.
http://www.space.com/3142-planets-defined.html

Web: Most familiar categories have simple labels such as planet or dog. However, more

complex categories can be made up for a particular purpose. Barsalou (1983) studied categories such as things to carry out of a burning house or ways to avoid being killed by the Mob. Interestingly, someone has published a book consisting of people's photographs of things they would carry out of a burning house, and there is also a website showing such collections. Try to analyze what is common to the category members. What is the category's prototype?
http://theburninghouse.com/

Discussion Questions

1. Pick a couple of familiar categories and try to come up with definitions for them. When you evaluate each proposal (a) is it in fact accurate as a definition, and (b) is it a definition that people might actually use in identifying category members?
2. For the same categories, can you identify members that seem to be "better" and "worse" members? What about these items makes them typical and atypical?
3. Going around the room, point to some common objects (including things people are wearing or brought with them) and identify what the basic-level category is for that item. What are superordinate and subordinate categories for the same items?
4. List some features of a common category such as tables. The knowledge view suggests that you know reasons for why these particular features occur together. Can you articulate some of those reasons? Do the same thing for an animal category.
5. Choose three common categories: a natural kind, a human artifact, and a social event. Discuss with class members from other countries or cultures whether the corresponding categories in their cultures differ. Can you make a hypothesis about when such categories are likely to differ and when they are not?

Vocabulary

Basic-level category
The neutral, preferred category for a given object, at an intermediate level of specificity.

Category
A set of entities that are equivalent in some way. Usually the items are similar to one another.

Concept
The mental representation of a category.

Exemplar
An example in memory that is labeled as being in a particular category.

Psychological essentialism
The belief that members of a category have an unseen property that causes them to be in the category and to have the properties associated with it.

Typicality
The difference in “goodness” of category members, ranging from the most typical (the prototype) to borderline members.

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12

Judgment and Decision Making

Max H. Bazerman

Humans are not perfect decision makers. Not only are we not perfect, but we depart from perfection or rationality in systematic and predictable ways. The understanding of these systematic and predictable departures is core to the field of judgment and decision making. By understanding these limitations, we can also identify strategies for making better and more effective decisions.

Learning Objectives

- Understand the systematic biases that affect our judgment and decision making.
- Develop strategies for making better decisions.
- Experience some of the biases through sample decisions.

Introduction

Every day you have the opportunity to make countless decisions: should you eat dessert, cheat on a test, or attend a sports event with your friends. If you reflect on your own history of choices you will realize that they vary in quality; some are rational and some are not. This module provides an overview of decision making and includes discussion of many of the common biases involved in this process.

In his Nobel Prize–winning work, psychologist Herbert Simon (1957; March & Simon, 1958) argued that our decisions are bounded in their rationality. According to the **bounded** rationality framework, human beings try to make rational decisions (such as weighing the costs and benefits of a choice) but our cognitive limitations prevent us from being fully rational. Time and cost constraints limit the quantity and quality of the information that is available to us. Moreover, we only retain a relatively small amount of information in our usable memory. And limitations on intelligence and perceptions constrain the ability of even very bright decision makers to accurately make the best choice based on the information that is available.

About 15 years after the publication of Simon's seminal work, Tversky and Kahneman (1973, 1974; Kahneman & Tversky, 1979) produced their own Nobel Prize–winning research, which provided critical information about specific systematic and predictable biases, or mistakes, that influence judgment (Kahneman received the prize after Tversky's death). The work of Simon, Tversky, and Kahneman paved the way to our modern understanding of judgment and decision making. And their two Nobel prizes signaled the broad acceptance of the field of behavioral decision research as a mature area of intellectual study.

What Would a Rational Decision Look Like?

People often have to use incomplete information and intuition to make even the most important of decisions. A fully rational decision requires a careful, systematic process. [Image: CC0 Public Domain, https://goo.gl/m25gce]

Imagine that during your senior year in college, you apply to a number of doctoral programs, law schools, or business schools (or another set of programs in whatever field most interests you). The good news is that you receive many acceptance letters. So, how should you decide where to go? Bazerman and Moore (2013) outline the following six steps that you should take to make a rational decision: (1) define the problem (i.e., selecting the right graduate program), (2) identify the criteria necessary to judge the multiple options (location, prestige, faculty, etc.), (3) weight the criteria (rank them in terms of importance to you), (4) generate alternatives (the schools that admitted you), (5) rate each alternative on each criterion (rate each school on each criteria that you identified, and (6) compute the optimal decision. Acting rationally would require that you follow these six steps in a fully rational manner.

I strongly advise people to think through important decisions such as this in a manner similar to this process. Unfortunately, we often don't. Many of us rely on our intuitions far more than we should. And when we do try to think systematically, the way we enter data into such formal decision-making processes is often biased.

Fortunately, psychologists have learned a great deal about the biases that affect our thinking. This knowledge about the systematic and predictable mistakes that even the best and the brightest make can help you identify flaws in your thought processes and reach better decisions.

Biases in Our Decision Process

Simon's concept of bounded rationality taught us that judgment deviates from rationality, but it did not tell us *how* judgment is biased. Tversky and Kahneman's (1974) research helped to diagnose the specific systematic, directional biases that affect human judgment. These biases are created by the tendency to short-circuit a rational decision process by relying on a number of simplifying strategies, or rules of thumb, known as **heuristics**. Heuristics allow us to cope with the complex environment surrounding our decisions. Unfortunately, they also lead to systematic and predictable biases.

To highlight some of these biases please answer the following three quiz items:

Problem 1 (adapted from Alpert & Raiffa, 1969):

Listed below are 10 uncertain quantities. Do not look up any information on these items. For each, write down your best estimate of the quantity. Next, put a lower and upper bound around your estimate, such that you are 98 percent confident that your range surrounds the actual quantity. Respond to each of these items even if you admit to knowing very little about these quantities.

1. The first year the Nobel Peace Prize was awarded
2. The date the French celebrate "Bastille Day"
3. The distance from the Earth to the Moon
4. The height of the Leaning Tower of Pisa
5. Number of students attending Oxford University (as of 2014)
6. Number of people who have traveled to space (as of 2013)

7. 2012-2013 annual budget for the University of Pennsylvania
8. Average life expectancy in Bangladesh (as of 2012)
9. World record for pull-ups in a 24-hour period
10. Number of colleges and universities in the Boston metropolitan area

Problem 2 (adapted from Joyce & Biddle, 1981):

We know that executive fraud occurs and that it has been associated with many recent financial scandals. And, we know that many cases of management fraud go undetected even when annual audits are performed. Do you think that the incidence of significant executive-level management fraud is more than 10 in 1,000 firms (that is, 1 percent) audited by Big Four accounting firms?

1. Yes, more than 10 in 1,000 Big Four clients have significant executive-level management fraud.
2. No, fewer than 10 in 1,000 Big Four clients have significant executive-level management fraud.

What is your estimate of the number of Big Four clients per 1,000 that have significant executive-level management fraud? (Fill in the blank below with the appropriate number.)

________ in 1,000 Big Four clients have significant executive-level management fraud.

Problem 3 (adapted from Tversky & Kahneman, 1981):

Imagine that the United States is preparing for the outbreak of an unusual avian disease that is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimates of the consequences of the programs are as follows.

1. Program A: If Program A is adopted, 200 people will be saved.
2. Program B: If Program B is adopted, there is a one-third probability that 600 people will be saved and a two-thirds probability that no people will be saved.

Which of the two programs would you favor?

Overconfidence

On the first problem, if you set your ranges so that you were justifiably 98 percent confident, you should expect that approximately 9.8, or nine to 10, of your ranges would include the actual value. So, let's look at the correct answers:

1. 1901
2. 14th of July
3. 384,403 km (238,857 mi)
4. 56.67 m (183 ft)
5. 22,384 (as of 2014)
6. 536 people (as of 2013)
7. $6.007 billion
8. 70.3 years (as of 2012)
9. 4,321
10. 52

Overconfidence is a natural part of most people's decision-making process and this can get us into trouble. Is it possible to overcome our faulty thinking? Perhaps. See the "Fixing Our Decisions" section below. [Image: Barn Images, https://goo.gl/IYzbDV, CC BY 2.0, https://goo.gl/BRvSA7]

Count the number of your 98% ranges that actually surrounded the true quantities. If you surrounded nine to 10, you were appropriately confident in your judgments. But most readers surround only between three (30%) and seven (70%) of the correct answers, despite claiming 98% confidence that each range would surround the true value. As this problem shows, humans tend to be overconfident in their judgments.

Anchoring

Regarding the second problem, people vary a great deal in their final assessment of the level of executive-level management fraud, but most think that 10 out of 1,000 is too low. When I run this exercise in class, half of the students respond to the question that I asked you to answer. The other half receive a similar problem, but instead are asked whether the correct answer is higher or lower than 200 rather than 10. Most people think that 200 is high. But, again, most people claim that this "anchor" does not affect their final estimate. Yet, on average, people who are presented with the question that focuses on the number 10 (out of 1,000) give answers that are about one-half the size of the estimates of those facing questions that use an anchor of 200. When we are making decisions, any initial anchor that we face is likely to influence our judgments, even if the anchor is arbitrary. That is, we insufficiently adjust our judgments away from the anchor.

Framing

Turning to Problem 3, most people choose Program A, which saves 200 lives for sure, over Program B. But, again, if I was in front of a classroom, only half of my students would receive this problem. The other half would have received the same set-up, but with the following two options:

1. Program C: If Program C is adopted, 400 people will die.
2. Program D: If Program D is adopted, there is a one-third probability that no one will die and a two-thirds probability that 600 people will die.

Which of the two programs would you favor?

Careful review of the two versions of this problem clarifies that they are objectively the same. Saving 200 people (Program A) means losing 400 people (Program C), and Programs B and D are also objectively identical. Yet, in one of the most famous problems in judgment and decision making, most individuals choose Program A in the first set and Program D in the second set (Tversky & Kahneman, 1981). People respond very differently to saving versus losing lives—even when the difference is based just on the "**framing**" of the choices.

The problem that I asked you to respond to was framed in terms of saving lives, and the implied reference point was the worst outcome of 600 deaths. Most of us, when we make decisions that concern gains, are risk averse; as a consequence, we lock in the possibility of saving 200 lives for sure. In the alternative version, the problem is framed in terms of losses. Now the implicit reference point is the best outcome of no deaths due to the avian disease. And in this case, most people are risk seeking when making decisions regarding losses.

These are just three of the many biases that affect even the smartest among us. Other research shows that we are biased in favor of information that is easy for our minds to retrieve, are insensitive to the importance of base rates and sample sizes when we are making inferences, assume that random events will always look random, search for information that confirms our expectations even when disconfirming information would be more informative, claim a priori knowledge that didn't exist due to the hindsight bias, and are subject to a host of other effects that continue to be developed in the literature (Bazerman & Moore, 2013).

Contemporary Developments

The concept of bounded willpower may explain why many of us are better shoppers than savers. [Image: CC0 Public Domain, https://goo.gl/m25gce]

Bounded rationality served as the integrating concept of the field of behavioral decision research for 40 years. Then, in 2000, Thaler (2000) suggested that decision making is bounded in two ways not precisely captured by the concept of bounded rationality. First, he argued that our **willpower is bounded** and that, as a consequence, we give greater weight to present concerns than to future concerns. Our immediate motivations are often inconsistent with our long-term interests in a variety of ways, such as the common failure to save adequately for retirement or the difficulty many people have staying on a diet. Second, Thaler suggested that our **self-interest is bounded** such that we care about the outcomes of others. Sometimes we positively value the outcomes of others—giving them more of a commodity than is necessary out of a desire to be fair, for example. And, in unfortunate contexts, we sometimes are willing to forgo our own benefits out of a desire to harm others.

My colleagues and I have recently added two other important bounds to the list. Chugh, Banaji, and Bazerman (2005) and Banaji and Bhaskar (2000) introduced the concept of **bounded ethicality**, which refers to the notion that our ethics are limited in ways we are not even aware of ourselves. Second, Chugh and Bazerman (2007) developed the concept of **bounded awareness** to refer to the broad array of focusing failures that affect our judgment, specifically the many ways in which we fail to notice obvious and important information that is available to us.

A final development is the application of judgment and decision-making research to the areas of behavioral economics, behavioral finance, and behavioral marketing, among others. In each case, these fields have been transformed by applying and extending research from the judgment and decision-making literature.

Fixing Our Decisions

Ample evidence documents that even smart people are routinely impaired by biases. Early research demonstrated, unfortunately, that awareness of these problems does little to reduce bias (Fischhoff, 1982). The good news is that more recent research documents interventions that do help us overcome our faulty thinking (Bazerman & Moore, 2013).

One critical path to fixing our biases is provided in Stanovich and West's (2000) distinction between **System 1** and **System 2** decision making. System 1 processing is our intuitive system, which is typically fast, automatic, effortless, implicit, and emotional. System 2 refers to decision making that is slower, conscious, effortful, explicit, and logical. The six logical steps of decision making outlined earlier describe a System 2 process.

Clearly, a complete System 2 process is not required for every decision we make. In most situations, our System 1 thinking is quite sufficient; it would be impractical, for example, to logically reason through every choice we make while shopping for groceries. But, preferably, System 2 logic should influence our most important decisions. Nonetheless, we use our System 1 processes for most decisions in life, relying on it even when making important decisions.

The key to reducing the effects of bias and improving our decisions is to transition from trusting our intuitive System 1 thinking toward engaging more in deliberative System 2 thought. Unfortunately, the busier and more rushed people are, the more they have on their minds, and the more likely they are to rely on System 1 thinking (Chugh, 2004). The frantic pace of professional life suggests that executives often rely on System 1 thinking (Chugh, 2004).

Fortunately, it is possible to identify conditions where we rely on intuition at our peril and substitute more deliberative thought. One fascinating example of this substitution comes from journalist Michael Lewis' (2003) account of how Billy Beane, the general manager of the Oakland Athletics, improved the outcomes of the failing baseball team after recognizing that the intuition of baseball executives was limited and systematically biased and that their intuitions had been incorporated into important decisions in ways that created enormous mistakes. Lewis (2003) documents that baseball professionals tend to overgeneralize from their personal experiences, be overly influenced by players' very recent performances, and overweigh what they see with their own eyes, despite the fact that players' multiyear records provide far better data. By substituting valid predictors of future performance (System 2 thinking), the Athletics were able to outperform expectations given their very limited payroll.

Nudges can be used to help people make better decisions about saving for retirement. [Image: Tax Credits, https://goo.gl/YLuyth, CC BY 2.0, https://goo.gl/BRvSA7]

Another important direction for improving decisions comes from Thaler and Sunstein's (2008) book *Nudge: Improving Decisions about Health, Wealth, and Happiness.* Rather than setting out to debias human judgment, Thaler and Sunstein outline a strategy for how "decision architects" can change environments in ways that account for human bias and trigger better decisions as a result. For example, Beshears, Choi, Laibson, and Madrian (2008) have shown that simple changes to defaults can dramatically improve people's decisions. They tackle the failure of many people to save for retirement and show that a simple change can significantly influence enrollment in 401(k) programs. In most companies, when you start your job, you need to proactively sign up to join the company's retirement savings plan. Many people take years before getting around to doing so. When, instead, companies automatically enroll their employees in 401(k) programs and give them the opportunity to "opt out," the net enrollment rate rises significantly. By changing defaults, we can counteract the human tendency to live with the status quo.

Similarly, Johnson and Goldstein's (2003) cross-European organ donation study reveals that countries that have opt-in organ donation policies, where the default is not to harvest people's organs without their prior consent, sacrifice thousands of lives in comparison to opt-out policies, where the default is to harvest organs. The United States and too many other countries require that citizens opt in to organ donation through a proactive effort; as a consequence, consent rates range between 4.25%–44% across these countries. In contrast, changing the decision architecture to an opt-out policy improves consent rates to 85.9% to 99.98%. Designing the donation system with knowledge of the power of defaults can dramatically change donation rates without changing the options available to citizens. In contrast, a more intuitive strategy, such as the one in place in the United States, inspires defaults that result in many unnecessary deaths.

Concluding Thoughts

Our days are filled with decisions ranging from the small (what should I wear today?) to the important (should we get married?). Many have real world consequences on our health, finances and relationships. Simon, Kahneman, and Tversky created a field that highlights the surprising and predictable deficiencies of the human mind when making decisions. As we understand more about our own biases and thinking shortcomings we can begin to take them into account or to avoid them. Only now have we reached the frontier of using this knowledge to help people make better decisions.

Outside Resources

Book: Bazerman, M. H., & Moore, D. (2013). Judgment in managerial decision making (8th ed.). John Wiley & Sons Inc.

Book: Kahneman, D. (2011) Thinking, Fast and Slow. New York, NY: Farrar, Straus and Giroux.

Book: Thaler, R. H., & Sunstein, C. R. (2008). Nudge: Improving Decisions about Health, Wealth, and Happiness. New Haven, CT: Yale University Press.

Discussion Questions

1. Are the biases in this module a problem in the real world?
2. How would you use this module to be a better decision maker?
3. Can you see any biases in today's newspaper?

Vocabulary

Anchoring
The bias to be affected by an initial anchor, even if the anchor is arbitrary, and to insufficiently adjust our judgments away from that anchor.

Biases
The systematic and predictable mistakes that influence the judgment of even very talented human beings.

Bounded awareness
The systematic ways in which we fail to notice obvious and important information that is available to us.

Bounded ethicality
The systematic ways in which our ethics are limited in ways we are not even aware of ourselves.

Bounded rationality
Model of human behavior that suggests that humans try to make rational decisions but are bounded due to cognitive limitations.

Bounded self-interest
The systematic and predictable ways in which we care about the outcomes of others.

Bounded willpower
The tendency to place greater weight on present concerns rather than future concerns.

Framing
The bias to be systematically affected by the way in which information is presented, while holding the objective information constant.

Heuristics
cognitive (or thinking) strategies that simplify decision making by using mental short-cuts

Overconfident
The bias to have greater confidence in your judgment than is warranted based on a rational assessment.

System 1
Our intuitive decision-making system, which is typically fast, automatic, effortless, implicit, and emotional.

System 2
Our more deliberative decision-making system, which is slower, conscious, effortful, explicit, and logical.

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13
Intelligence

Robert Biswas-Diener

Intelligence is among the oldest and longest studied topics in all of psychology. The development of assessments to measure this concept is at the core of the development of psychological science itself. This module introduces key historical figures, major theories of intelligence, and common assessment strategies related to intelligence. This module will also discuss controversies related to the study of group differences in intelligence.

Learning Objectives

- List at least two common strategies for measuring intelligence.
- Name at least one "type" of intelligence.
- Define intelligence in simple terms.
- Explain the controversy relating to differences in intelligence between groups.

Introduction

Every year hundreds of grade school students converge on Washington, D.C., for the annual Scripps National Spelling Bee. The "bee" is an elite event in which children as young as 8 square off to spell words like "cymotrichous" and "appoggiatura." Most people who watch the bee think of these kids as being "smart" and you likely agree with this description.

What makes a person intelligent? Is it heredity (two of the 2014 contestants in the bee have siblings who have previously won)(National Spelling Bee, 2014a)? Is it interest (the most frequently listed favorite subject among spelling bee competitors is math)(NSB, 2014b)? In this module we will cover these and other fascinating aspects of **intelligence**. By the end of the module you should be able to define intelligence and discuss some common strategies for measuring intelligence. In addition, we will tackle the politically thorny issue of whether there are differences in intelligence between groups such as men and women.

A participant in the Scripps National Spelling Bee. [Image: Scripps National Spelling Bee, https://goo.gl/94Hgbm, CC BY-NC 2.0, https://goo.gl/VnKlK8]

Defining and Measuring Intelligence

When you think of "smart people" you likely have an intuitive sense of the qualities that make them intelligent. Maybe you think they have a good memory, or that they can think quickly, or that they simply know a whole lot of information. Indeed, people who exhibit such qualities appear very intelligent. That said, it seems that intelligence must be more than simply knowing facts and being able to remember them. One point in favor of this argument is the idea of animal intelligence. It will come as no surprise to you that a dog, which can learn commands and tricks seems smarter than a snake that cannot. In fact, researchers and lay people generally agree with one another that primates—monkeys and apes (including humans)—are among the most intelligent animals. Apes such as chimpanzees are capable of complex problem solving and sophisticated communication (Kohler, 1924).

Scientists point to the social nature of primates as one evolutionary source of their intelligence. Primates live together in troops or family groups and are, therefore, highly social creatures. As such, primates tend to have brains that are better developed for communication and long term thinking than most other animals. For instance, the complex social environment has led primates to develop deception, altruism, numerical concepts, and "theory of mind" (a sense of the self as a unique individual separate from others in the group; Gallup, 1982; Hauser, MacNeilage & Ware, 1996).[Also see Noba module Theory of Mind **http://noba.to/a8wpytg3]**

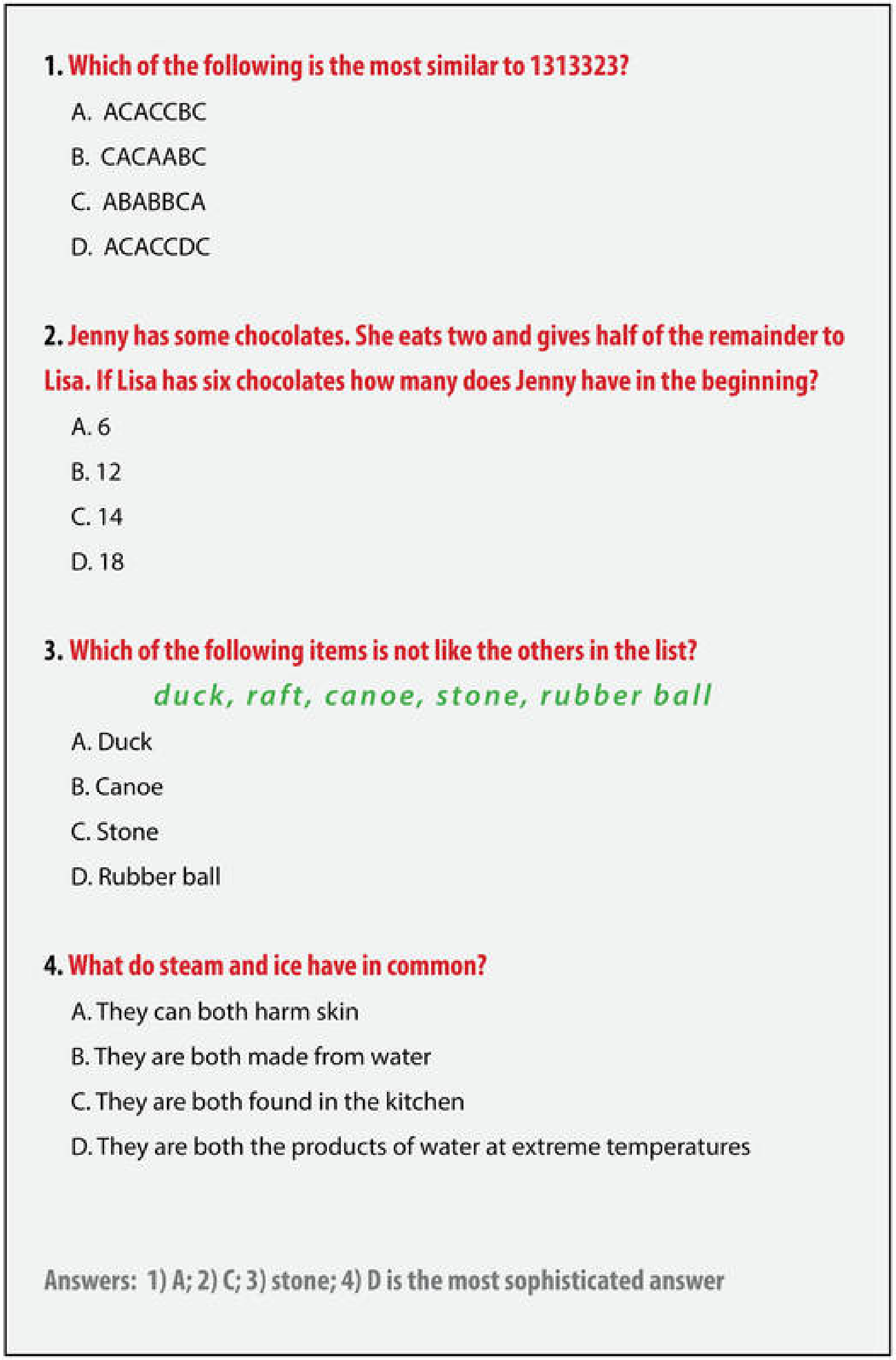
The question of what constitutes human intelligence is one of the oldest inquiries in psychology. When we talk about intelligence we typically mean intellectual ability. This broadly encompasses the ability to learn, remember and use new information, to solve problems and to adapt to novel situations. An early scholar of intelligence, Charles Spearman, proposed the idea that intelligence was one thing, a “general factor” sometimes known as simply “g.” He based this conclusion on the observation that people who perform well in one intellectual area such as verbal ability also tend to perform well in other areas such as logic and reasoning (Spearman, 1904).

A contemporary of Spearman’s named Francis Galton—himself a cousin of Charles Darwin--was among those who pioneered psychological measurement (Hunt, 2009). For three pence Galton would measure various physical characteristics such as grip strength but also some psychological attributes such as the ability to judge distance or discriminate between colors. This is an example of one of the earliest systematic measures of individual ability. Galton was particularly interested in intelligence, which he thought was heritable in much the same way that height and eye color are. He conceived of several rudimentary methods for assessing whether his hypothesis was true. For example, he carefully tracked the family tree of the top-scoring Cambridge students over the previous 40 years. Although he found specific families disproportionately produced top scholars, intellectual achievement could still be the product of economic status, family culture or other non-genetic factors. Galton was also, possibly, the first to popularize the idea that the heritability of psychological traits could be studied by looking at identical and fraternal twins. Although his methods were crude by modern standards, Galton established intelligence as a variable that could be measured (Hunt, 2009).

Intelligence research pioneer Alfred Binet

The person best known for formally pioneering the measurement of intellectual ability is Alfred Binet. Like Galton, Binet was fascinated by individual differences in intelligence. For instance, he blindfolded chess players and saw that some of them had the ability to continue playing using only their memory to keep the many positions of the pieces in mind (Binet, 1894). Binet was particularly interested in the development of intelligence, a fascination that led him to observe children carefully in the classroom setting.

Along with his colleague Theodore Simon, Binet created a test of children’s intellectual capacity. They created individual test items that should be answerable by children of given ages. For instance, a child who is three should be able to point to her mouth and eyes, a child who is nine should be able to name the months of the year in order, and a twelve year old ought to be able to name sixty words in three minutes. Their assessment became the first “IQ test."



1. Which of the following is the most similar to 1313323?

A. ACACCBC
B. CACAABC
C. ABABBCA
D. ACACCDC

2. Jenny has some chocolates. She eats two and gives half of the remainder to Lisa. If Lisa has six chocolates how many does Jenny have in the beginning?

A. 6
B. 12
C. 14
D. 18

3. Which of the following items is not like the others in the list?

duck, raft, canoe, stone, rubber ball

A. Duck
B. Canoe
C. Stone
D. Rubber ball

4. What do steam and ice have in common?

A. They can both harm skin
B. They are both made from water
C. They are both found in the kitchen
D. They are both the products of water at extreme temperatures

Answers: 1) A; 2) C; 3) stone; 4) D is the most sophisticated answer

Table 1: Examples of the types of items you might see on an intelligence test.

"IQ" or "intelligence quotient" is a name given to the score of the Binet-Simon test. The score is derived by dividing a child's mental age (the score from the test) by their chronological age to create an overall quotient. These days, the phrase "IQ" does not apply specifically to the Binet-Simon test and is used to generally denote intelligence or a score on any intelligence test. In the early 1900s the Binet-Simon test was adapted by a Stanford professor named Lewis Terman to create what is, perhaps, the most famous intelligence test in the world, the Stanford-Binet (Terman, 1916). The major advantage of this new test was that it was standardized. Based on a large sample of children Terman was able to plot the scores in a normal distribution, shaped like a "bell curve" (see Fig. 1). To understand a normal distribution think about the height of people. Most people are average in height with relatively fewer being tall or short, and fewer still being extremely tall or extremely short. Terman (1916) laid out intelligence scores in exactly the same way, allowing for easy and reliable categorizations and comparisons between individuals.

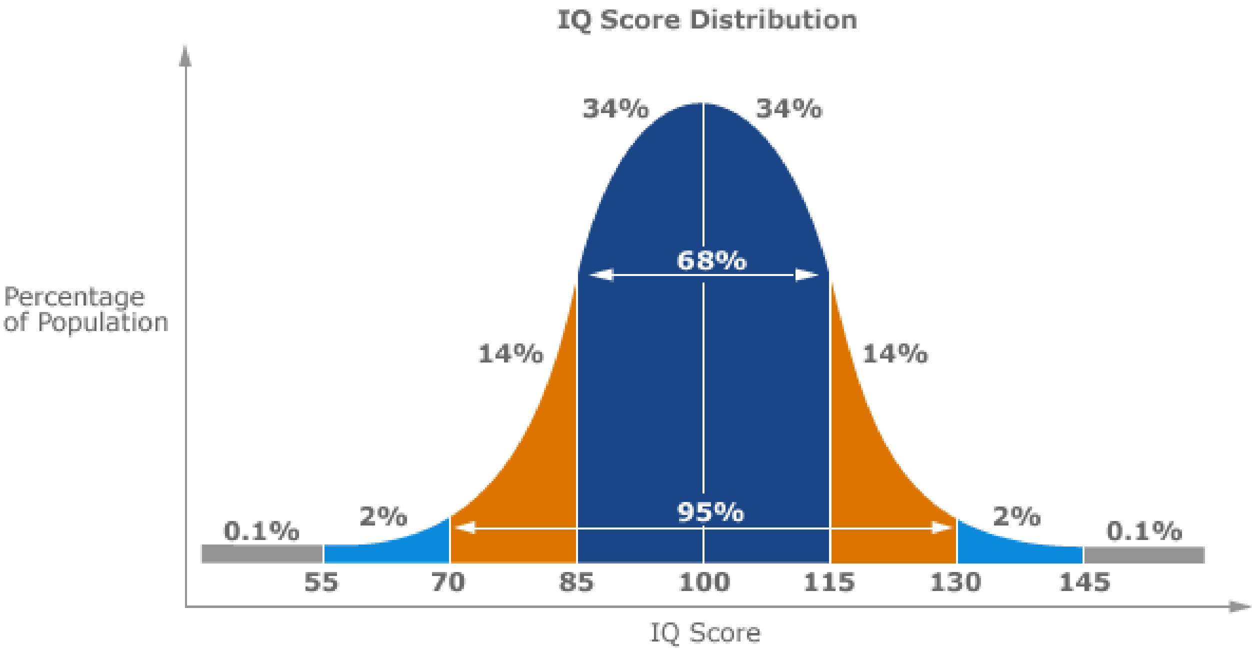


Figure 1: Bell Curve - Normal Distribution IQ

Looking at another modern intelligence test—the Wechsler Adult Intelligence Scale (WAIS)—can provide clues to a definition of intelligence itself. Motivated by several criticisms of the Stanford-Binet test, psychologist David Wechsler sought to create a superior measure of intelligence. He was critical of the way that the Stanford-Binet relied so heavily on verbal ability and was also suspicious of using a single score to capture all of intelligence. To address these issues Wechsler created a test that tapped a wide range of intellectual abilities. This understanding of intelligence—that it is made up of a pool of specific abilities—is a notable departure from Spearman's concept of general intelligence. The WAIS assesses people's ability to remember, compute, understand language, reason well, and process information quickly (Wechsler, 1955).

One interesting by-product of measuring intelligence for so many years is that we can chart changes over time. It might seem strange to you that intelligence can change over the decades but that appears to have happened over the last 80 years we have been measuring this topic. Here's how we know: IQ tests have an average score of 100. When new waves of people are asked to take older tests they tend to outperform the original sample from years ago on which the test was normed. This gain is known as the "Flynn Effect," named after James Flynn, the researcher who first identified it (Flynn, 1987). Several hypotheses have been put forth to explain the Flynn Effect including better nutrition (healthier brains!), greater familiarity with testing in general, and more exposure to visual stimuli. Today, there is no perfect agreement among psychological researchers with regards to the causes of increases in average scores on intelligence tests. Perhaps if you choose a career in psychology you will be the one to discover the answer!

Types of Intelligence

David Wechsler's approach to testing intellectual ability was based on the fundamental idea that there are, in essence, many aspects to intelligence. Other scholars have echoed this idea by going so far as to suggest that there are actually even different types of intelligence. You likely have heard distinctions made between "street smarts" and "book learning." The former refers to practical wisdom accumulated through experience while the latter indicates formal education. A person high in street smarts might have a superior ability to catch a person in a lie, to persuade others, or to think quickly under pressure. A person high in book learning, by contrast, might have a large vocabulary and be able to remember a large number of references to classic novels. Although psychologists don't use street smarts or book smarts as professional terms they do believe that intelligence comes in different types.

There are many ways to parse apart the concept of intelligence. Many scholars believe that Carroll 's (1993) review of more than 400 data sets provides the best currently existing single source for organizing various concepts related to intelligence. Carroll divided intelligence into three levels, or strata, descending from the most abstract down to the most specific (see Fig. 2). To understand this way of categorizing simply think of a "car." Car is a general word that denotes all types of motorized vehicles. At the more specific level under "car" might be various types of cars such as sedans, sports cars, SUVs, pick-up trucks, station wagons, and so forth. More specific still would be certain models of each such as a Honda Civic or Ferrari Enzo. In the same manner, Carroll called the highest level (stratum III) the general intelligence factor "g." Under this were more specific stratum II categories such as fluid intelligence and visual perception and processing speed. Each of these, in turn, can be sub-divided into very specific components such as spatial scanning, reaction time, and word fluency.

Thinking of intelligence as Carroll (1993) does, as a collection of specific mental abilities, has helped researchers conceptualize this topic in new ways. For example, Horn and Cattell (1966) distinguish between "fluid" and "crystalized" intelligence, both of which show up on stratum II of Carroll's model. Fluid intelligence is the ability to "think on your feet;" that is, to solve problems. Crystalized intelligence, on the other hand, is the ability to use language, skills and experience to address problems. The former is associated more with youth while the latter increases with age. You may have noticed the way in which younger people can adapt to new situations and use trial and error to quickly figure out solutions. By contrast, older people tend to rely on their relatively superior store of knowledge to solve problems.

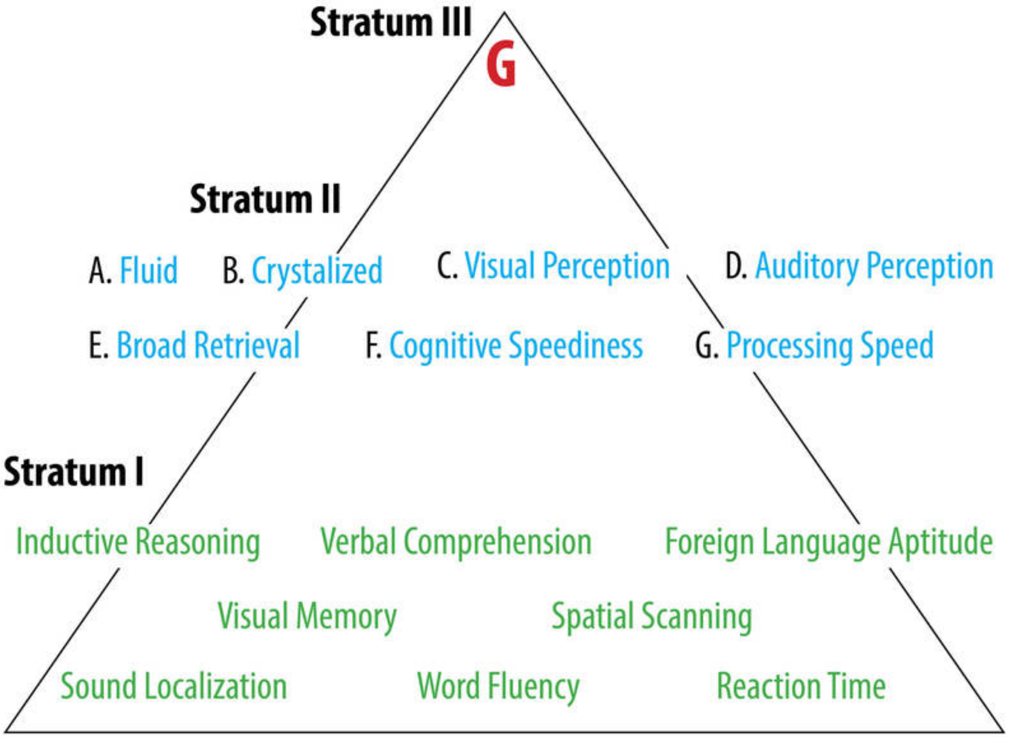


Figure 2: Caroll's Model of Intelligence

Harvard professor Howard Gardner is another figure in psychology who is well-known for championing the notion that there are different types of intelligence. Gardner's theory is appropriately, called "multiple intelligences." Gardner's theory is based on the idea that people process information through different "channels" and these are relatively independent of one another. He has identified 8 common intelligences including 1) logic-math, 2) visual-spatial, 3) music-rhythm, 4) verbal-linguistic, 5) bodily-kinesthetic, 6) interpersonal, 7) intrapersonal, and 8) naturalistic (Gardner, 1985). Many people are attracted to Gardner's theory because it suggests that people each learn in unique ways. There are now many Gardner- influenced schools in the world.

Another type of intelligence is Emotional intelligence. Unlike traditional models of intelligence that emphasize cognition (thinking) the idea of emotional intelligence emphasizes the experience and expression of emotion. Some researchers argue that emotional intelligence is a set of skills in which an individual can accurately understand the emotions of others, can identify and label their own emotions, and can use emotions. (Mayer & Salovey, 1997). Other researchers believe that emotional intelligence is a mixture of abilities, such as stress management, and personality, such as a person's predisposition for certain moods (Bar-On, 2006). Regardless of the specific definition of emotional intelligence, studies have shown a link between this concept and job performance (Lopes, Grewal, Kadis, Gall, & Salovey, 2006). In fact, emotional intelligence is similar to more traditional notions of cognitive intelligence with regards to workplace benefits. Schmidt and Hunter (1998), for example, reviewed research on intelligence in the workplace context and show that intelligence is the single best predictor of doing well in job training programs, of learning on the job. They also report that general intelligence is moderately correlated with all types of jobs but especially with managerial and complex, technical jobs.

There is one last point that is important to bear in mind about intelligence. It turns out that the way an individual thinks about his or her own intelligence is also important because it predicts performance. Researcher Carol Dweck has made a career out of looking at the differences between high IQ children who perform well and those who do not, so-called "under achievers." Among her most interesting findings is that it is not gender or social class that sets apart the high and low performers. Instead, it is their mindset. The children who believe that their abilities in general—and their intelligence specifically—is a fixed trait tend to underperform. By contrast, kids who believe that intelligence is changeable and evolving tend to handle failure better and perform better (Dweck, 1986). Dweck refers to this as a person's "mindset" and having a growth mindset appears to be healthier.

Correlates of Intelligence

The research on mindset is interesting but there can also be a temptation to interpret it as suggesting that every human has an unlimited potential for intelligence and that becoming smarter is only a matter of positive thinking. There is some evidence that genetics is an important factor in the intelligence equation. For instance, a number of studies on genetics in adults have yielded the result that intelligence is largely, but not totally, inherited (Bouchard,2004). Having a healthy attitude about the nature of smarts and working hard can both definitely help intellectual performance but it also helps to have the genetic leaning toward intelligence.

Carol Dweck's research on the mindset of children also brings one of the most interesting and controversial issues surrounding intelligence research to the fore: group differences. From the very beginning of the study of intelligence researchers have wondered about differences between groups of people such as men and women. With regards to potential differences between the sexes some people have noticed that women are under-represented in certain fields. In 1976, for example, women comprised just 1% of all faculty members in engineering (Ceci, Williams & Barnett, 2009).

Women account for a disproportionately small percentage of those employed in math-intensive career fields such as engineering. [Photo: Argonne National Laboratory, https://goo.gl/ix96YP, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

Even today women make up between 3% and 15% of all faculty in math-intensive fields at the 50 top universities. This phenomenon could be explained in many ways: it might be the result of inequalities in the educational system, it might be due to differences in socialization wherein young girls are encouraged to develop other interests, it might be the result of that women are—on average—responsible for a larger portion of childcare obligations and therefore make different types of professional decisions, or it might be due to innate differences between these groups, to name just a few possibilities. The possibility of innate differences is the most controversial because many people see it as either the product of or the foundation for sexism. In today's political landscape it is easy to see that asking certain questions such as "are men smarter than women?" would be inflammatory. In a comprehensive review of research on intellectual abilities and sex Ceci and colleagues (2009) argue against the hypothesis that biological and genetic differences account for much of the sex differences in intellectual ability. Instead, they believe that a complex web of influences ranging from societal expectations to test taking strategies to individual interests account for many of the sex differences found in math and similar intellectual abilities.

A more interesting question, and perhaps a more sensitive one, might be to inquire in which ways men and women might differ in intellectual ability, if at all. That is, researchers should not seek to prove that one group or another is better but might examine the ways that they might differ and offer explanations for any differences that are found. Researchers have investigated sex differences in intellectual ability. In a review of the research literature Halpern (1997) found that women appear, on average, superior to men on measures of fine motor skill, acquired knowledge, reading comprehension, decoding non-verbal expression, and generally have higher grades in school. Men, by contrast, appear, on average, superior to women on measures of fluid reasoning related to math and science, perceptual tasks that involve moving objects, and tasks that require transformations in working memory such as mental rotations of physical spaces. Halpern also notes that men are disproportionately represented on the low end of cognitive functioning including in intellectual disability , dyslexia, and attention deficit disorders (Halpern, 1997).

Other researchers have examined various explanatory hypotheses for why sex differences in intellectual ability occur. Some studies have provided mixed evidence for genetic factors while others point to evidence for social factors (Neisser, et al, 1996; Nisbett, et al., 2012). One interesting phenomenon that has received research scrutiny is the idea of **stereotype threat**. Stereotype threat is the idea that mental access to a particular stereotype can have real-world impact on a member of the stereotyped group. In one study (Spencer, Steele, & Quinn, 1999), for example, women who were informed that women tend to fare poorly on math exams just before taking a math test actually performed worse relative to a control group who did not hear the stereotype. Research on stereotype has yielded mixed results and we are currently uncertain about exactly how and when this effect might occur. One possible antidote to stereotype threat, at least in the case of women, is to make a self-affirmation (such as listing positive personal qualities) before the threat occurs. In one study, for instance, Martens and her colleagues (2006) had women write about personal qualities that they valued before taking a math test. The affirmation largely erased the effect of stereotype by improving math scores for women relative to a control group but similar affirmations had little effect for men (Martens, Johns, Greenberg, & Schimel, 2006).

These types of controversies compel many lay people to wonder if there might be a problem with intelligence measures. It is natural to wonder if they are somehow biased against certain groups. Psychologists typically answer such questions by pointing out that bias in the testing sense of the word is different than how people use the word in everyday speech. Common use of bias denotes a prejudice based on group membership. Scientific bias, on the other hand, is related to the psychometric properties of the test such as validity and reliability.

Validity is the idea that an assessment measures what it claims to measure and that it can predict future behaviors or performance. To this end, intelligence tests are not biased because they are fairly accurate measures and predictors. There are, however, real biases, prejudices, and inequalities in the social world that might benefit some advantaged group while hindering some disadvantaged others.

Conclusion

Although you might not be able to spell “esquamulose” or “staphylococci” – indeed, you might not even know what they mean—you don’t need to count yourself out in the intelligence department. Now that we have examined intelligence in depth we can return to our intuitive view of those students who compete in the National Spelling Bee. Are they smart? Certainly, they seem to have high verbal intelligence. There is also the possibility that they benefit from either a genetic boost in intelligence, a supportive social environment, or both. Watching them spell difficult words there is also much we do not know about them. We cannot tell, for instance, how emotionally intelligent they are or how they might use bodily-kinesthetic intelligence. This highlights the fact that intelligence is a complicated issue. Fortunately, psychologists continue to research this fascinating topic and their studies continue to yield new insights.

Outside Resources

Blog: Dr. Jonathan Wai has an excellent blog on Psychology Today discussing many of the most interesting issue related to intelligence.
http://www.psychologytoday.com/blog/finding-the-next-einstein

Video: Hank Green gives a fun and interesting overview of the concept of intelligence in this installment of the Crash Course series.
https://www.youtube.com/watch?v=9xTz3QjcloI

Discussion Questions

1. Do you think that people get smarter as they get older? In what ways might people gain or lose intellectual abilities as they age?
2. When you meet someone who strikes you as being smart what types of cues or information do you typically attend to in order to arrive at this judgment?
3. How do you think socio-economic status affects an individual taking an intellectual abilities test?
4. Should psychologists be asking about group differences in intellectual ability? What do you think?
5. Which of Howard Gardner’s 8 types of intelligence do you think describes the way you learn best?

Vocabulary

G
Short for “general factor” and is often used to be synonymous with intelligence itself.

Intelligence
An individual’s cognitive capability. This includes the ability to acquire, process, recall and apply information.

IQ
Short for “intelligence quotient.” This is a score, typically obtained from a widely used measure of intelligence that is meant to rank a person’s intellectual ability against that of others.

Norm
Assessments are given to a representative sample of a population to determine the range of scores for that population. These “norms” are then used to place an individual who takes that assessment on a range of scores in which he or she is compared to the population at large.

Standardize
Assessments that are given in the exact same manner to all people . With regards to intelligence tests standardized scores are individual scores that are computed to be referenced against normative scores for a population (see “norm”).

Stereotype threat
The phenomenon in which people are concerned that they will conform to a stereotype or that their performance does conform to that stereotype, especially in instances in which the stereotype is brought to their conscious awareness.

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14

Consciousness

Ken Paller & Satoru Suzuki

Consciousness is the ultimate mystery. What is it and why do we have it? These questions are difficult to answer, even though consciousness is so fundamental to our existence. Perhaps the natural world could exist largely as it is without human consciousness; but taking away consciousness would essentially take away our humanity. Psychological science has addressed questions about consciousness in part by distinguishing neurocognitive functions allied with conscious experience from those that transpire without conscious experience. The continuing investigation of these sorts of distinctions is yielding an empirical basis for new hypotheses about the precursors of conscious experience. Richer conceptualizations are thus being built, combining first-person and third-person perspectives to provide new clues to the mystery of consciousness

Learning Objectives

- Understand scientific approaches to comprehending consciousness.
- Be familiar with evidence about human vision, memory, body awareness, and decision making relevant to the study of consciousness.
- Appreciate some contemporary theories about consciousness.

Conscious Experiences

Contemplate the unique experience of being you at this moment! You, and only you, have direct knowledge of your own conscious experiences. At the same time, you cannot know consciousness from anyone else's inside view. How can we begin to understand this fantastic ability to have private, conscious experiences?

At the most basic level all of conscious experience is unique to each individual. [Image: Étienne Ljóni Poisson, https://goo.gl/mbo5VJ, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

In a sense, everything you know is from your own vantage point, with your own consciousness at the center. Yet the scientific study of consciousness confronts the challenge of producing general understanding that goes beyond what can be known from one individual's perspective.

To delve into this topic, some terminology must first be considered. The term *consciousness* can denote the ability of a person to generate a series of conscious experiences one after another. Here we include experiences of feeling and understanding sensory input, of a temporal sequence of autobiographical events, of imagination, of emotions and moods, of ideas, of memories—the whole range of mental contents open to an individual.

Consciousness can also refer to the state of an individual, as in a sharp or dull state of consciousness, a drug-induced state such as euphoria, or a diminished state due to drowsiness, sleep, neurological abnormality, or coma. In this module, we focus not on states of consciousness or on self-consciousness, but rather on the process that unfolds in the course of a conscious experience—a moment of awareness—the essential ingredient of consciousness.

Other Minds

You have probably experienced the sense of knowing exactly what a friend is thinking. Various signs can guide our inferences about consciousness in others. We can try to infer what's going on in someone else's mind by relying on the assumption that they feel what we imagine we would feel in the same situation. We might account for someone's actions or emotional expressions through our knowledge of that individual and our careful observations of their behavior. In this way, we often display substantial insight into what they are thinking. Other times we are completely wrong.

By measuring brain activity using various neuroscientific technologies, we can acquire additional information useful for deciphering another person's state of mind. In special circumstances such inferences can be highly accurate, but limitations on mind reading remain, highlighting the difficulty of understanding exactly how conscious experiences arise.

A Science of Consciousness

Attempts to understand consciousness have been pervasive throughout human history, mostly dominated by philosophical analyses focused on the first-person perspective. Now we have a wider set of approaches that includes philosophy, psychology, neuroscience, cognitive science, and contemplative science (Blackmore, 2006; Koch, 2012; Zelazo, Moscovitch, & Thompson, 2007; Zeman, 2002).

The challenge for this combination of approaches is to give a comprehensive explanation of consciousness. That explanation would include describing the benefits of consciousness, particularly for behavioral capabilities that conscious experiences allow, that trump automatic behaviors. Subjective experiences also need to be described in a way that logically shows how they result from precursor events in the human brain. Moreover, a full account would describe how consciousness depends on biological, environmental, social, cultural, and developmental factors.

Consciousness is a topic that has been addressed by religious scholars, philosophers, psychologists, and neuroscientists. [Image: CC0 Public Domain, https://goo.gl/m25gce]

At the outset, a central question is how to conceive of consciousness relative to other things we know. Objects in our environment have a physical basis and are understood to be composed of constituents, such that they can be broken down into molecules, elements, atoms, particles, and so on. Yet we can also understand things relationally and conceptually. Sometimes a phenomenon can best be conceived as a process rather than a physical entity (e.g., digestion is a process whereby food is broken down). What, then, is the relationship between our conscious thoughts and the physical universe, and in particular, our brains?

Rene Descartes’ position, *dualism*, was that mental and physical are, in essence, different substances. This view can be contrasted with *reductionist views* that mental phenomena can be explained via descriptions of physical phenomena. Although the dualism/reductionism debate continues, there are many ways in which mind can be shown to depend on brain.

A prominent orientation to the scientific study of consciousness is to seek understanding of these dependencies—to see how much light they can shed on consciousness. Significant advances in our knowledge about consciousness have thus been gained, as seen in the following examples.

Conscious Experiences of Visual Perception

Suppose you meet your friend at a crowded train station. You may notice a subtle smile on her face. At that moment you are probably unaware of many other things happening within your view. What makes you aware of some things but not others? You probably have your own intuitions about this, but experiments have proven wrong many common intuitions about what generates visual awareness.

Are you really aware of everything that is going on around you? In the context of a crowded train station you may be visually aware of certain things while essentially being blind to many others that are right in front of you. [Image: Diego Torres Silvestre, https://goo.gl/ZkCWEC, CC BY 2.0, https://goo.gl/BRvSA7]

For instance, you may think that if you attentively look at a bright spot, you must be aware of it. Not so. In a phenomenon known as motion-induced blindness, bright discs completely vanish from your awareness in full attention. To experience this for yourself, see this module's Outside Resource section for a demonstration of motion-induced blindness.

You may think that if you deeply analyze an image, decoding its meaning and making a decision about it, you must be aware of the image. Not necessarily. When a number is briefly flashed and rapidly replaced by a random pattern, you may have no awareness of it, despite the fact that your brain allows you to determine that the number is greater than 5, and then prepare your right hand for a key press if that is what you were instructed to do (Dehaene et al., 1998).

Thus, neither the brightness of an image, paying full attention to it, nor deeply analyzing it guarantees that you will be aware of it. What, then, is the crucial ingredient of visual awareness?

A contemporary answer is that our awareness of a visual feature depends on a certain type of reciprocal exchange of information across multiple brain areas, particularly in the cerebral cortex. In support of this idea, directly activating your visual motion area (known as V5) with an externally applied magnetic field (*transcranial magnetic stimulation*) will make you see moving dots. This is not surprising. What is surprising is that activating your visual motion area alone does not let you see motion. You will not see moving dots if the feedback signal from V5 to the primary visual cortex is disrupted by a further transcranial magnetic stimulation pulse (Pascual-Leone & Walsh, 2001). The reverberating reciprocal exchange of information between higher-level visual areas and primary visual cortex appears to be essential for generating visual awareness.

This idea can also explain why people with certain types of brain damage lack visual awareness. Consider a patient with brain damage limited to primary visual cortex who claims not to see anything — a problem termed *cortical blindness*. Other areas of visual cortex may still receive visual input through projections from brain structures such as the thalamus and superior colliculus, and these networks may mediate some preserved visual abilities that take place without awareness. For example, a patient with cortical blindness might detect moving stimuli via V5 activation but still have no conscious experiences of the stimuli, because the reverberating reciprocal exchange of information cannot take place between V5 and the damaged primary visual cortex. The preserved ability to detect motion might be evident only when a guess is required ("guess whether something moved to the left or right")—otherwise the answer would be "I didn't see anything." This phenomenon of blindsight refers to blindness due to a neurological cause that preserves abilities to analyze and respond to visual stimuli that are not consciously experienced (Lamme, 2001).

If exchanges of information across brain areas are crucial for generating visual awareness, neural synchronization must play an important role because it promotes neural communication. A neuron's excitability varies over time. Communication among neural populations is enhanced when their oscillatory cycles of excitability are synchronized. In this way, information transmitted from one population in its excitable phase is received by the target population when it is also in its excitable phase. Indeed, oscillatory neural synchronization in the beta- and gamma-band frequencies (identified according to the number of oscillations per second, 13–30 Hz and 30–100 Hz, respectively) appears to be closely associated with visual awareness. This idea is highlighted in the *Global Neuronal Workspace*

Theory of Consciousness (Dehaene & Changeux, 2011), in which sharing of information among prefrontal, inferior parietal, and occipital regions of the cerebral cortex is postulated to be especially important for generating awareness.

A related view, the *Information Integration Theory of Consciousness*, is that shared information itself constitutes consciousness (Tononi, 2004). An organism would have minimal consciousness if the structure of shared information is simple, whereas it would have rich conscious experiences if the structure of shared information is complex. Roughly speaking, complexity is defined as the number of intricately interrelated informational units or ideas generated by a web of local and global sharing of information. The degree of consciousness in an organism (or a machine) would be high if numerous and diversely interrelated ideas arise, low if only a few ideas arise or if there are numerous ideas but they are random and unassociated. Computational analyses provide additional perspectives on such proposals. In particular, if every neuron is connected to every other neuron, all neurons would tend to activate together, generating few distinctive ideas. With a very low level of neuronal connectivity at the other extreme, all neurons would tend to activate independently, generating numerous but unassociated ideas. To promote a rich level of consciousness, then, a suitable mixture of short-, medium-, and long-range neural connections would be needed. The human cerebral cortex may indeed have such an optimum structure of neural connectivity. Given how consciousness is conceptualized in this theory as graded rather than all-or-none, a quantitative approach (e.g., Casali et al., 2013; Monti et al., 2013) could conceivably be used to estimate the level of consciousness in nonhuman species and artificial beings.

Conscious Experiences of Memory

The pinnacle of conscious human memory functions is known as episodic recollection because it allows one to reexperience the past, to virtually relive an earlier event. People who suffer from amnesia due to neurological damage to certain critical brain areas have poor memory for events and facts. Their memory deficit disrupts the type of memory termed *declarative memory* and makes it difficult to consciously remember. However, amnesic insults typically spare a set of memory functions that do not involve conscious remembering. These other types of memory, which include various habits, motor skills, cognitive skills, and procedures, can be demonstrated when an individual executes various actions as a function of prior learning, but in these cases a conscious experience of remembering is not necessarily included.

Research on amnesia has thus supported the proposal that conscious remembering requires a specific set of brain operations that depend on networks of neurons in the cerebral cortex.

Memory is one basis for conscious awareness. [Image: CC0 Public Domain, https://goo.gl/m25gce]

Some of the other types of memory involve only subcortical brain regions, but there are also notable exceptions. In particular, *perceptual priming* is a type of memory that does not entail the conscious experience of remembering and that is typically preserved in amnesia. Perceptual priming is thought to reflect a fluency of processing produced by a prior experience, even when the individual cannot remember that prior experience. For example, a word or face might be perceived more efficiently if it had been viewed minutes earlier than if it hadn't. Whereas a person with amnesia can demonstrate this item-specific fluency due to changes in corresponding cortical areas, they nevertheless would be impaired if asked to recognize the words or faces they previously experienced. A reasonable conclusion on the basis of this evidence is that remembering an episode is a conscious experience not merely due to the involvement of one portion of the cerebral cortex, but rather due to the specific configuration of cortical activity involved in the sharing or integration of information.

Further neuroscientific studies of memory retrieval have shed additional light on the necessary steps for conscious recollection. For example, storing memories for the events we experience each day appears to depend on connections among multiple cortical regions as well as on a brain structure known as the hippocampus. Memory storage becomes more secure due to interactions between the hippocampus and cerebral cortex that can transpire over extended time periods following the initial registration of information. Conscious retrieval thus depends on the activity of elaborate sets of networks in the cortex. Memory retrieval that does not include conscious recollection depends either on restricted portions of the cortex or on brain regions separate from the cortex.

The ways in which memory expressions that include the awareness of remembering differ from those that do not thus highlight the special nature of conscious memory experiences (Paller, Voss, & Westerberg, 2009; Voss, Lucas, & Paller, 2012). Indeed, memory storage in the brain can be very complex for many different types of memory, but there are specific physiological prerequisites for the type of memory that coincides with conscious recollection.

Conscious Experiences of Body Awareness

The brain can generate body awareness by registering coincident sensations. For example, when you rub your arm, you see your hand rubbing your arm and simultaneously feel the rubbing sensation in both your hand and your arm. This simultaneity tells you that it is *your* hand and *your* arm. Infants use the same type of coincident sensations to initially develop the self/nonself distinction that is fundamental to our construal of the world.

The fact that your brain constructs body awareness in this way can be experienced via the rubber-hand illusion (see Outside Resource on this). If you see a rubber hand being rubbed and simultaneously feel the corresponding rubbing sensation on your own body out of view, you will momentarily feel a bizarre sensation—that the rubber hand is your own.

The construction of our body awareness appears to be mediated by specific brain mechanisms involving a region of the cortex known as the temporoparietal junction. Damage to this brain region can generate distorted body awareness, such as feeling a substantially elongated torso. Altered neural activity in this region through artificial stimulation can also produce an out-of-body experience (see this module's Outside Resources section), in which you feel like your body is in another location and you have a novel perspective on your body and the world, such as from the ceiling of the room.

Remarkably, comparable brain mechanisms may also generate the normal awareness of the sense of self and the sensation of being inside a body. In the context of *virtual reality* this sensation is known as *presence* (the compelling experience of actually being there). Our normal localization of the self may be equally artificial, in that it is not a given aspect of life but is constructed through a special brain mechanism.

A *Social Neuroscience Theory of Consciousness* (Graziano & Kastner, 2011) ascribes an important role to our ability to localize our own sense of self. The main premise of the theory is that you fare better in a social environment to the extent that you can predict what people are going to do. So, the human brain has developed mechanisms to construct models of other people's attention and intention, and to localize those models in the corresponding people's heads to keep track of them. The proposal is that the same brain mechanism was adapted to construct a model of one's own attention and intention, which is then localized in one's own head and perceived as consciousness. If so, then the primary function of consciousness is to allow us to predict our own behavior. Research is needed to test the major predictions of this new theory, such as whether changes in consciousness (e.g., due to normal fluctuations, psychiatric disease, brain damage) are closely associated with changes in the brain mechanisms that allow us to model other people's attention and intention.

Conscious Experiences of Decision Making

Choosing among multiple possible actions, the sense of *volition*, is closely associated with our subjective feeling of consciousness. When we make a lot of decisions, we may feel especially conscious and then feel exhausted, as if our mental energy has been drained.

We make decisions in two distinct ways. Sometimes we carefully analyze and weigh different factors to reach a decision, taking full advantage of the brain's conscious mode of information processing. Other times we make a *gut decision*, trusting the unconscious mode of information processing (although it still depends on the brain). The unconscious mode is adept at simultaneously considering numerous factors in parallel, which can yield an overall impression of the sum total of evidence. In this case, we have no awareness of the individual considerations. In the conscious mode, in contrast, we can carefully scrutinize each factor—although the act of focusing on a specific factor can interfere with weighing in other factors.

When making a decision you might carefully consider your choices or simply "go with your gut". [Image: Daniel Lee, https://goo.gl/aJi3jx, CC BY-NC-SA 2.0, https://goo.gl/Toc0ZF]

One might try to optimize decision making by taking into account these two strategies. A careful conscious decision should be effective when there are only a few known factors to consider. A gut decision should be effective when a large number of factors should be considered simultaneously. Gut decisions can indeed be accurate on occasion (e.g., guessing which of many teams will win a close competition), but only if you are well versed in the relevant domain (Dane, Rockmann, & Pratt, 2012).

As we learn from our experiences, some of this gradual knowledge accrual is unconscious; we don't know we have it and we can use it without knowing it. On the other hand, consciously acquired information can be uniquely beneficial by allowing additional stages of control (de Lange, van Gaal, Lamme, & Dehaene, 2011). It is often helpful to control which new knowledge we acquire and which stored information we retrieve in accordance with our conscious goals and beliefs.

Whether you choose to trust your gut or to carefully analyze the relevant factors, you feel that you freely reach your own decision. Is this feeling of free choice real? Contemporary experimental techniques fall short of answering this existential question. However, it is likely that at least the sense of immediacy of our decisions is an illusion.

In one experiment, people were asked to freely consider whether to press the right button or the left button, and to press it when they made the decision (Soon, Brass, Heinze, & Haynes, 2008). Although they indicated that they made the decision immediately before pressing the button, their brain activity, measured using functional magnetic resonance imaging, predicted their decision as much as 10 seconds before they said they freely made the decision. In the same way, each conscious experience is likely preceded by precursor brain events that on their own do not entail consciousness but that culminate in a conscious experience.

In many situations, people generate a reason for an action that has nothing to do with the actual basis of the decision to act in a particular way. We all have a propensity to retrospectively produce a reasonable explanation for our behavior, yet our behavior is often the result of unconscious mental processing, not conscious volition.

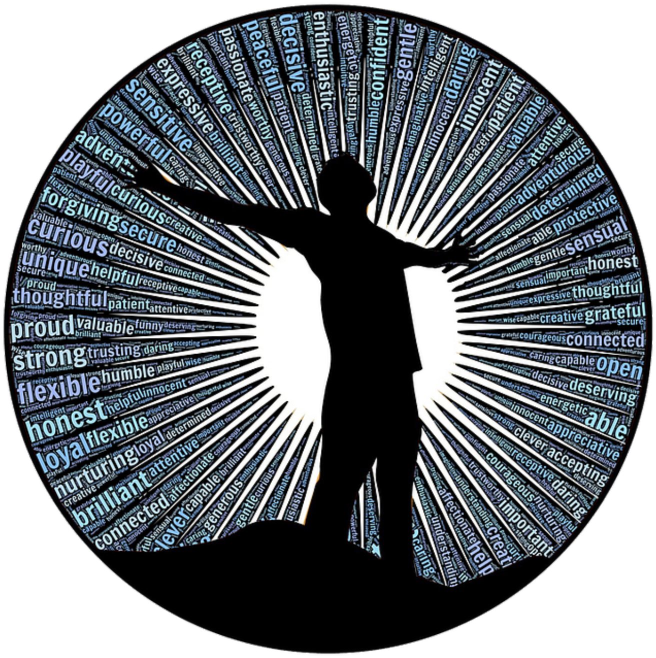
Why do we feel that each of our actions is immediately preceded by our own decision to act? This illusion may help us distinguish our own actions from those of other agents. For example, while walking hand-in-hand with a friend, if you felt you made a decision to turn left immediately before you both turned left, then you know that you initiated the turn; otherwise, you would know that your friend did.

Even if some aspects of the decision-making process are illusory, to what extent are our decisions determined by prior conditions? It certainly seems that we can have full control of some decisions, such as when we create a conscious intention that leads to a specific action: You can decide to go left or go right. To evaluate such impressions, further research must develop a better understanding of the neurocognitive basis of volition, which is a tricky undertaking, given that decisions are conceivably influenced by unconscious processing, neural noise, and the unpredictability of a vast interactive network of neurons in the brain.

Yet belief in free choice has been shown to promote moral behavior, and it is the basis of human notions of justice. The sense of free choice may be a beneficial trait that became prevalent because it helped us flourish as social beings.

Understanding Consciousness

Our human consciousness unavoidably colors all of our observations and our attempts to gain understanding. Nonetheless, scientific inquiries have provided useful perspectives on consciousness. The advances described above should engender optimism about the various research strategies applied to date and about the prospects for further insight into consciousness in the future.



Because conscious experiences are inherently private, they have sometimes been taken to be outside the realm of scientific inquiry. This view idealizes science as an endeavor involving only observations that can be verified by multiple observers, relying entirely on the **third-person perspective**, or the view from nowhere (from no particular perspective). Yet conducting science is a human activity that depends, like other human activities, on individuals and their subjective experiences. A rational scientific account of the world cannot avoid the fact that people have subjective experiences.

Subjectivity thus has a place in science. Conscious experiences can be subjected to systematic analysis and empirical tests to yield progressive understanding. Many further questions remain to be addressed by scientists of the future. Is the first-person perspective of a conscious experience basically the same for all human beings, or do individuals differ fundamentally in their introspective experiences and capabilities? Should psychological science focus only on ordinary experiences of consciousness, or are extraordinary experiences also relevant? Can training in introspection lead to a specific sort of expertise with respect to conscious experience? An individual with training, such as through extensive meditation practice, might be able to describe their experiences in a more precise manner, which could then support improved characterizations of consciousness. Such a person might be able to understand subtleties of experience that other individuals fail to notice, and thereby move our understanding of consciousness significantly forward. These and other possibilities await future scientific inquiries into consciousness.

Outside Resources

1. Video: Demonstration of motion-induced blindness - Look steadily at the blue moving pattern. One or more of the yellow spots may disappear.
http://www.youtube.com/watch?v=4Aye9FWgxUg

2. Web: Learn more about motion-induced blindness on Michael Bach\\\'s website
http://www.michaelbach.de/ot/mot-mib/index.html

3. Video: Clip showing a patient with blindsight, from the documentary \\\"Phantoms in the Brain.\\\"
http://youtu.be/Cy8FSffrNDI

4. Video: Clip on the rubber hand illusion, from the BBC science series \\\"Horizon.\\\"
http://www.youtube.com/watch?v=Qsmkgi7FgEo

5. Video: Clip on out-of-body experiences induced using virtual reality.
http://www.youtube.com/watch?v=4PQAc_Z2OfQ

6. App: Visual illusions for the iPad.
http://www.exploratorium.edu/explore/apps/color-uncovered

7. Web: Definitions of Consciousness
http://www.consciousentities.com/definitions.htm

8. Video: The mind-body problem - An interview with Ned Block
http://vimeo.com/58254376

9. Video: Imaging the Brain, Reading the Mind - A talk by Marsel Mesulam.
https://www.youtube.com/watch?v=Xp_LXwZns6Q&feature=youtu.be

Video: Ted Talk - Simon Lewis: Don't take consciousness for granted
http://www.ted.com/talks/simon_lewis_don_t_take_consciousness_for_granted.html

Discussion Questions

1. Why has consciousness evolved? Presumably it provides some beneficial capabilities for

an organism beyond behaviors that are based only on automatic triggers or unconscious processing. What are the likely benefits of consciousness?

2. How would you explain to a congenitally blind person the experience of seeing red? Detailed explanations of the physics of light and neurobiology of color processing in the brain would describe the mechanisms that give rise to the experience of seeing red, but would not convey the experience. What would be the best way to communicate the subjective experience itself?
3. Our visual experiences seem to be a direct readout of information from the world that comes into our eyes, and we usually believe that our mental representations give us an accurate and exact re-creation of the world. Is it possible that what we consciously perceive is not veridical, but is a limited and distorted view, in large part a function of the specific sensory and information-processing abilities that the brain affords?
4. When are you most conscious—while you're calm, angry, happy, or moved; while absorbed in a movie, video game, or athletic activity; while engaged in a spirited conversation, making decisions, meditating, reflecting, trying to solve a difficult problem, day dreaming, or feeling creative? How do these considerations shed light on what consciousness is?
5. Consciousness may be a natural biological phenomenon and a chief function of a brain, but consider the many ways in which it is also contingent on (i) a body linked with a brain, (ii) an outside world, (iii) a social environment, and (iv) a developmental trajectory. How do these considerations enrich our understanding of consciousness?
6. Conscious experiences may not be limited to human beings. However, the difficulty of inferring consciousness in other beings highlights the limitations of our current understanding of consciousness. Many nonhuman animals may have conscious experiences; pet owners often have no doubt about what their pets are thinking. Computers with sufficient complexity might at some point be conscious—but how would we know?

Vocabulary

Awareness
A conscious experience or the capability of having conscious experiences, which is distinct from self-awareness, the conscious understanding of one's own existence and individuality.

Conscious experience
The first-person perspective of a mental event, such as feeling some sensory input, a memory, an idea, an emotion, a mood, or a continuous temporal sequence of happenings.

Contemplative science
A research area concerned with understanding how contemplative practices such as meditation can affect individuals, including changes in their behavior, their emotional reactivity, their cognitive abilities, and their brains. Contemplative science also seeks insights into conscious experience that can be gained from first-person observations by individuals who have gained extraordinary expertise in introspection.

First-person perspective
Observations made by individuals about their own conscious experiences, also known as introspection or a subjective point of view. Phenomenology refers to the description and investigation of such observations.

Third-person perspective
Observations made by individuals in a way that can be independently confirmed by other individuals so as to lead to general, objective understanding. With respect to consciousness, third-person perspectives make use of behavioral and neural measures related to conscious experiences.

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Index

ablate, 29
absolute threshold, 40
agnosia, 44
anchor, 195
anosmia, 50
anterograde amnesia, 150
audition, 46
auditory canal, 46
auditory hair cells, 46
autobiographical memory, 110
awareness, 222
basal ganglia, 26
basic level of categorization, 178
Behaviorism, 11
biases, 192
binocular advantage, 70
binocular disparity, 43
binocular vision, 43
bottom-up processing, 42
bounded awareness, 197
bounded ethicality, 197
bounded rationality, 192
brain stem, 24
callosotomy, 27
case studies, 29
category, 172
cerebellum, 24
cerebral cortex, 25
cerebral hemispheres, 25
cerebrum, 24
chemical senses, 49
chunk, 134
classical conditioning, 132
cochlea, 46
cognitive psychology, 10
concepts, 172
cones, 44, 65
conscious experience, 222
consciousness, 8
consolidated, 147
consolidation, 115
contemplative science, 223
contralateral, 27
contrast, 66
contrast gain, 69
converging evidence, 28
cue overload principle, 118
dark adaptation, 44, 69
decay, 146
declarative memory, 150
dichotic listening, 83, 96
differential threshold, 41
Diffuse optical imaging (DOI), 31
dissociative amnesia, 151
distinctiveness, 111
divided attention, 82
dorsal pathway, 44
Electroencephalography (EEG), 31
empiricism, 6
encoding, 110, 134, 146
encoding specificity principle, 117
engrams, 114
episodic memory, 109
eugenics, 10
exemplar, 180
false memories, 163
first-person perspective, 223
flashbulb memory, 11, 112

flavor, 51
foils, 161
framing, 196
frontal lobe, 26
Functional magnetic resonance imaging (fMRI), 30
functionalism, 9
g, 208
Gestalt psychology, 10
gray matter, 27
gustation, 49
gyri, 25
gyrus, 25
habituation, 132
heuristics, 193
implicit learning, 132
implicit memory, 132
inattentional blindness, 98
inattentional deafness, 99
incidental learning, 134
individual differences, 10
intelligence, 207
intentional learning, 134
interference, 148
introspection, 8
IQ, 210
just noticeable difference (JND), 41
lateral inhibition, 68
lateralized, 27
lesions, 29
light adaptation, 45
limbic system, 26
limited capacity, 81
mechanoreceptors, 48
medial temporal lobes, 150
memory traces, 114
metabolites, 23
Metacognition, 136
misinformation effect, 116, 159
mnemonic devices, 121
mock witnesses, 161
motor cortex, 26
multimodal perception, 51
myelin, 27
neural impulse, 7
nociception, 49
nomenclature, 24
nonassociative learning, 132
normed, 211
occipital lobe, 25
Odorants, 50
olfaction, 49
olfactory epithelium, 50
operant conditioning, 132
Opponent Process theory of color, 71
opponent-process theory, 45
ossicles, 46
overconfident, 195
parietal lobe, 26
perception, 40
perceptual learning, 132
phantom limb pain, 49
phantom limbs, 49
photo spreads, 161
photoactivation, 65
phrenology, 28
pinna, 46
Positron emission tomography (PET), 30
primary auditory cortex, 47
primary somatosensory cortex, 48
primary visual cortex, 44, 69
principle of inverse effectiveness, 51
psychological essentialism, 183
psychophysics, 7
recoding, 112
retina, 43
retrieval, 110, 147
retroactive interference, 116

Retrograde amnesia, 150
rods, 44, 65
schemata, 163
scholar-practitioner model, 13
scientist-practitioner model, 13
selective attention, 82
selective listening, 96
self-interest is bounded, 197
Semantic memory, 109
sensation, 40
sensitization, 132
sensory adaptation, 42
shadowing, 83
shape theory of olfaction, 50
signal detection, 41
Somatosensation, 47
somatosensory (body sensations) cortex, 26
somatotopic map, 48
sound waves, 46
spatial resolution, 29
split-brain patients, 27
standardized, 210
stereotype threat, 215
storage, 110
structuralism, 8
subcortical, 25
sulci, 25
sulcus, 25
superadditive effect of multisensory integration, 51
synesthesia, 73
System 1, 198
System 2, 198
tastants, 50
taste receptor cells, 50
temporal lobe, 26
temporal resolution, 29
temporally graded retrograde amnesia, 150
third-person perspective, 231
tip-of-the-tongue phenomenon, 11
top-down processing, 42
Transcranial direct current stimulation (tDCS), 29
Transcranial magnetic stimulation (TMS), 29
transduction, 40
transfer-appropriate processing, 136
Trichromacy theory, 71
trichromatic theory, 45
tympanic membrane, 46
typical, 175
ventral pathway, 44
vestibular system, 47
vestibulo-ocular reflex, 73
visual hemifield, 27
Weber’s Law, 41
What pathway, 70
Where-and-How pathway, 70
white matter, 27
willpower is bounded, 197
working memory, 133